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of the
American Association *of* Petroleum Geologists

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BULLETIN
of the
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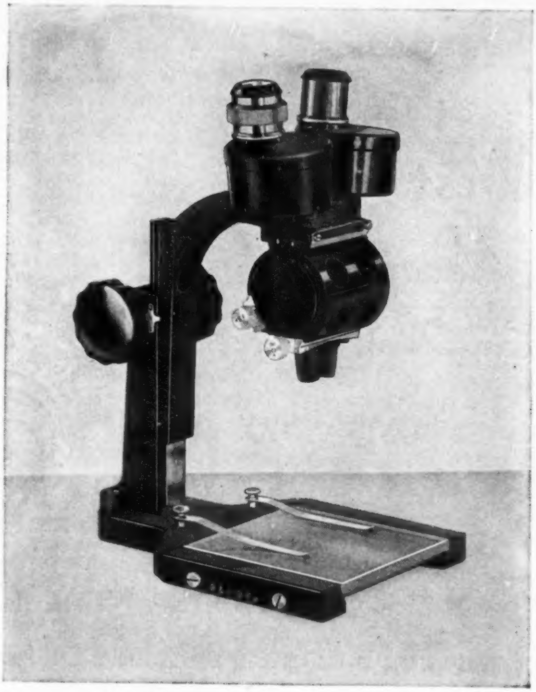

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APRIL, 1939

STRATIGRAPHIC STUDIES OF BAKER-GLENDIVE ANTICLINE, EASTERN MONTANA[1]

F. W. DeWOLF[2] AND W. W. WEST[3]
Urbana, Illinois, and Midland, Texas

ABSTRACT

The Northern Pacific Railroad Company well No. 1, drilled with rotary tools in 1935–1936 by the Montana-Dakota Utilities Company to the depth of 8,186 feet on the Baker-Glendive anticline of eastern Montana, following geophysical exploration of the subsurface, revealed that strata above the Pennsylvanian are similar to those of the Black Hills section except that 350 feet of salt was found in the Spearfish formation (or possibly the Permian). However, between the top of the Minnelusa formation at 5,631 feet and the top of the Madison at 7,440 feet, there are present 1,325 feet of beds representing the Big Snowy group of central Montana, as described in 1935 by H. W. Scott. The Madison appears to extend to a depth of about 8,055 feet, and the strata below that depth may represent the Devonian. Considerable help with correlations was offered by a restudy of samples from the Sinclair Prairie Oil Company's Westphal well drilled in 1931 on the Porcupine dome, 135 miles northwest of the Northern Pacific well.

It appears that the Big Snowy geosyncline of Mississippian age extends east at least to the Northern Pacific well No. 1 and has a length of at least 375 miles.

Oil was produced from the Northern Pacific well between 6,747 and 6,796 feet from the Big Snowy formation, and also from 8,130 to 8,186 feet from beds that may be Devonian in age.

INTRODUCTION

Three deep wells were drilled with rotary tools in 1935–1937 on the Baker-Glendive (Cedar Creek) anticline in Fallon County, southeastern Montana by the Montana-Dakota Utilities Company and have added greatly to a knowledge of the stratigraphy of the area.

Drilling of the first and deepest well, the Northern Pacific No. 1 (Sec. 17, T. 4 N., R. 62 E.) was begun in September, 1935; the well was shut down on account of weather conditions in February and March, 1936; and encountered promising oil production at a depth of 6,747 feet in April, 1936. Casing was set and tests were made before

[1] Read by title before the Association at New Orleans, March 18, 1938. Manuscript received, October 21, 1938.

[2] Professor of geology, and consulting geologist, University of Illinois.

[3] Geologist, Skelly Oil Company; formerly with Montana-Dakota Utilities Company, Baker, Montana.

and after acidizing. Water appeared and drilling was resumed in July. In August, 1936, additional saturation was found at 8,130–8,186 feet. Casing was set and small production, free from water, was obtained from a finely porous dolomite. The second well, Warren No. 1, located about 25 miles northwest (Sec. 23, T. 8 N., R. 58 E.) was drilled to 7,360 feet; and the third, Smith No. 1, located near the first well (Sec. 8, T. 4 N., R. 62 E.) reached a depth of 6,811 feet.

The Northern Pacific well, in particular, was sampled almost continuously and cored at close intervals. It was surveyed with Schlumberger apparatus and tested with Halliburton drill-stem tester. Experienced geologists,[4] constantly on duty, examined cores and cuttings microscopically. A. H. Sutton, of the department of geology and geography of the University of Illinois, has determined the age of the fossils where possible, and Harold W. Scott, of the same department, has given advice freely based on his knowledge of the paleontology and stratigraphy of the Big Snowy group.

The writers desire to commend the excellent technical control of the drilling operations by Cecil W. Smith, chief engineer, and H. A. Schroth, field superintendent, and to thank the company for the privilege of presenting this paper, which has been requested by geologists of the Rocky Mountain area.

The Baker-Glendive (Cedar Creek) anticline extends from Yellowstone River, near Glendive, Montana, southeastward about 100 miles, crossing the southwest corner of North Dakota and entering the northwest corner of South Dakota.

The general character of the surface structure and the presence of natural gas in it has been known since a gas well was completed in 1914. In 1922 the United States Geological Survey issued a press notice giving the results of investigations by G. F. Moulton and N. W. Bass, under the general direction of W. T. Thom, Jr. In 1934 the Survey published a geologic and structure contour map, as prepared by C. E. Dobbin, C. E. Erdmann, and R. M. Larsen.

Gas has been produced from this structure and supplied to the surrounding territory for many years, and more than 200 wells have been drilled. Production is considered to be from the Judith River sand of the Upper Cretaceous, at an average depth of about 800 feet. The gas is dry, and essentially methane, and no oil has previously been obtained from any of the wells. A deep test for oil was drilled in 1918 at the north end of the structure to a depth of 4,104 feet. It reached the Dakota sandstone at 3,920 feet. Another test to 4,187 feet at the south end of the structure reached the Dakota at 3,910 feet

[4] W. W. West, W. C. Rauch, and D. M. Allen.

and penetrated the Morrison about 75 feet. These were the deepest wells in eastern Montana. In the Northern Pacific well No. 1, herein described, the Dakota was topped at 3,724 feet and the drilling was continued 4,462 feet below this point.

GEOPHYSICAL SURVEY

It seemed desirable, because of certain characteristics of the surface structure, to make a geophysical survey of the subsurface structure of the anticline before choosing a location for a deep test. As contoured on a key bed at the top of the Pierre shale, it is strongly asymmetrical. The west flank dips locally as much as 1,000 feet in one mile, and is closely bordered on the west by a syncline, approximately 2–3 miles from the anticlinal axis. In contrast, the east flank commonly dips 50 feet, exceptionally 200 feet, to the mile, and is many miles wide. Since the axis of an asymmetrical anticline commonly migrates with depth toward the gentle limb it seemed desirable to determine the true conditions. Another important consideration was the subsurface magnitude of certain surface domes which occur along the axis of the anticline. Seven such domes are mapped, but four have not to exceed 50 feet of closure, two have not to exceed 100 feet, and one, Little Beaver dome, the southernmost, has more than 550 feet of closure and also the maximum altitude. It was desirable to learn whether any or all of the domes become more pronounced with increasing depth, for the facts might determine whether oil would probably be trapped in each, or would pass on to the Little Beaver dome. Similarly, it was important to learn whether certain faults shown on surface maps become stronger and more extensive with depth, so as to have increased importance in the control of oil migration. Because of these considerations arrangement was made with the Colorado Geophysical Corporation to make a seismograph survey by the reflection method.

The area covered by the survey was about 42 miles long and 3–5 miles wide. A cross section of the surface structure was made first, beginning near the well of the Absaroka Oil Development Company, in Sec. 24, T. 4 N., R. 61 E. Comparison of the reflections with the log of the well, which had reached the Dakota sandstones at 3,910 feet, confirmed the magnitude and general character of the surface fold. A longitudinal reflection profile was eventually carried the entire length of the area surveyed, and the equivalents of eight to ten cross sections were run to determine the magnitude of the domes along the axis, the depth of the intervening saddles, and the details of the faulting in the northwestern part of the area.

Reflections were obtained in the early work from five horizons, but the later work was concentrated on the Dakota sandstone and a bed calculated to be about 4,550 feet below it. In the subsequent drilling of the Northern Pacific well No. 1 the positions of the several reflecting beds corresponded, respectively, with (1) a "shell" 100 feet below the Greenhorn horizon, (2) the Dakota sandstone, (3) an 8-foot limestone in the Spearfish red shale and about 150 feet below the top, and (4) a dolomitic limestone, 100 feet below the top of the Minnelusa sandstone, and possibly corresponding with the top of the Amsden formation. The fifth horizon should have been reached at about 8,241 feet, or 55 feet below the bottom of the well. Due to the dependence of such surveys on assumed velocities, a permissible error in calculating the depth of a deep reflecting bed must be conceded. However, structure-contour maps based on all reflections from the second and the fifth beds, respectively, were so similar as to carry conviction of a high degree of accuracy.

In general, it may be stated that the structure is remarkably similar whether contoured on surface beds, the first gas sand, the Dakota, or the deepest reflecting bed. According to the deepest reflections there are a few more domes of smaller size along the axis and there appears to be about 50 per cent more closure on the better defined small domes, as compared with the surface structure. The survey was not extended far enough southeast along the Little Beaver dome to determine its maximum closure. There is no evidence of a great migration of the axis of the main anticline with depth, but if the reflections are accepted literally, the Little Beaver dome is double-crested at the Dakota horizon and lower, and a similar tendency appears in the extreme northerly end of the surveyed area. However, it should be noted that on Little Beaver the synclinal area between the axes is only 75–100 feet deep. At the north end of the surveyed area the irregularity is still milder. Possibly inaccuracy of method and operation is responsible and the apparent details of the reflection structures are not real.

The first test well was located on the gentle northeast limb of Little Beaver dome reasonably near its highest point and far enough from the axis so that a slight migration of the axis with depth or the wandering of a slightly crooked hole would not bring the bottom of the well southwest of the axis.

PREPARATION FOR CORRELATION OF SAMPLES

The writers, together with their associate W. E. Rauch, spent about 10 days in the Black Hills examining the section and collecting a set of samples typical of the outcropping formations from the

Mowry shale down to and including the top of the Madison limestone. Although the well location was about 90 miles due north of the north end of the Hills, no closer locality for obtaining samples was available. In this work helpful information was obtained from J. J. Runner of the University of Iowa and from research papers written by graduate students at that institution. Of course full use was made of publications by N. H. Darton and others of the United States Geological Survey. The northern end of the Big Horn Mountains was visited also for examination and sampling of Pennsylvanian and Mississippian formations exposed on Little Sheep Mountain. At a much later date during the drilling of the well a set of cuttings and cores from the Sinclair Prairie Oil Company's Westphal Permit well No. 1 on Porcupine dome, Montana, was obtained and studied by the junior writer to great advantage. Thanks are extended for this privilege to F. A. Bush, of the Sinclair Prairie Oil Company, Tulsa, Oklahoma.

SECTION TO THE MINNELUSA

A generalized log, as carefully recorded by the geologists, has been freely distributed to interested parties and has shown the interpretation of formation boundaries down to the top of the Minnelusa at 5,631 feet. A summary of the log is here presented.

Depth in Feet	*Formation Name*	*Character*
0– 528		Gray shale
– 717	Judith River (?)	Gas sand and shale
–1,167	Claggett (?)	Shale and a little sand
–1,199	Eagle (?)	Second gas sand
–3,724	Colorado	Shale, mostly; fish scales, 3,150–3,405; sandstones, 3,345–52, 3,405–33
–3,933	Dakota-Lakota	Sandstone and shale and pink shale (Fuson)
–4,025	Morrison	Variegated shale; green sandy shale
–4,586	Sundance	Greenish shale with considerable sandstone and some limestone; cross-bedded, rippled; belemnites and oyster shells
–4,785	Spearfish	Red shale, anhydrite, green shale, brown fossiliferous limestone
–5,000	Spearfish	Red shale, a little anhydrite, a little sand, traces of limestone
–5,360	Spearfish	Red shale, salt, traces of anhydrite
–5,463	Spearfish	Red shale, traces of anhydrite
–5,490	Minnekahta	Limestone resembling Black Hills equivalent
–5,631	Opeche	Red shale, traces anhydrite
–5,733	Minnelusa (Tensleep)	White cross-bedded sandstone; in middle, some dolomite

The salt, occurring plentifully through 360 feet of section, has not been reported in this region before. It has been assumed that this is Spearfish (Triassic) in age, but certain evidence suggests the possibility that it may be Permian. There may be an unconformity at the base of a sandstone extending from 4,833 to 4,867 feet, for in the Northern Pacific well No. 1 the salt begins 150 feet beneath the

sandstone while in the Warren well, on the northwest, the salt begins only 30 feet under the same sandstone, and the sandstone itself is much thicker. Possibly the salt belongs beneath a post-Permian unconformity.

UPPER MISSISSIPPIAN SECTION

Following the generalized table, in which the correlations offer no present problem, attention is directed to Figure 1, showing sections, and to the further discussion of lower formations encountered in the Northern Pacific No. 1. The locations of the sections are indicated by the small index map of the state.

Section 1 is in the Big Snowy Mountains, Sec. 6, T. 12 N., R. 20 E., as measured by Scott.[5] It illustrates the Big Snowy group at the type locality, beneath the Amsden, including the three formations in ascending order, Kibbey, Otter, and Heath. Scott emphasizes the occurrence of black shales in the Heath and of green shales in the Otter. The Otter limestones are in many places oölitic. The thin limestone at 582–585 feet is a well marked *Productus* zone at the top of the Otter. The overlying basal shale of the Heath contains the only Mississippian conodonts so far reported in the state.

Section 2 is also in the Big Snowy Mountains, T. 12 N., R. 22 E., 12–15 miles east of Section 1, as measured instrumentally by D. M. Collingwood for the senior writer, in 1919. Attention is called to black and green shales. Oölitic limestone occurs in the Otter, and gypsum in the Kibbey. Fossils were not collected.

Section 3 is the original log of the Van Duzen well in the Devil's basin as obtained in 1919. It was drilled with cable tools in Sec. 24, T. 11 N., R. 24 E. The Van Duzen "sand" (limestone) at 1,167 feet is, according to Scott, in the upper Heath. The "grass-green" shale at 1,455–1,465 feet impressed the drillers by its vividness.

Section 4 is a log prepared from the junior writer's study of cores and samples from the Sinclair Prairie Oil Company's Westphal Permit No. 1, on the Porcupine dome, in Sec. 26, T. 10 N., R. 39 E.

Section 5 is prepared from the cores and cuttings from the Montana-Dakota Utilities Company's Northern Pacific Railroad Company No. 1, in Sec. 17, T. 4 N., R. 62 E.

Section 6 is from *United States Geol. Survey Folio 107*, "New Castle, Wyoming," and represents a well at the Cambria mines.

The Mississippian in the Northern Pacific well No 1, Section 5, is

[5] Harold W. Scott, "Some Carboniferous Stratigraphy in Montana and Northwestern Wyoming," *Jour. Geol.*, Vol. 43, No. 8, Part II (November–December, 1935), p. 1011.

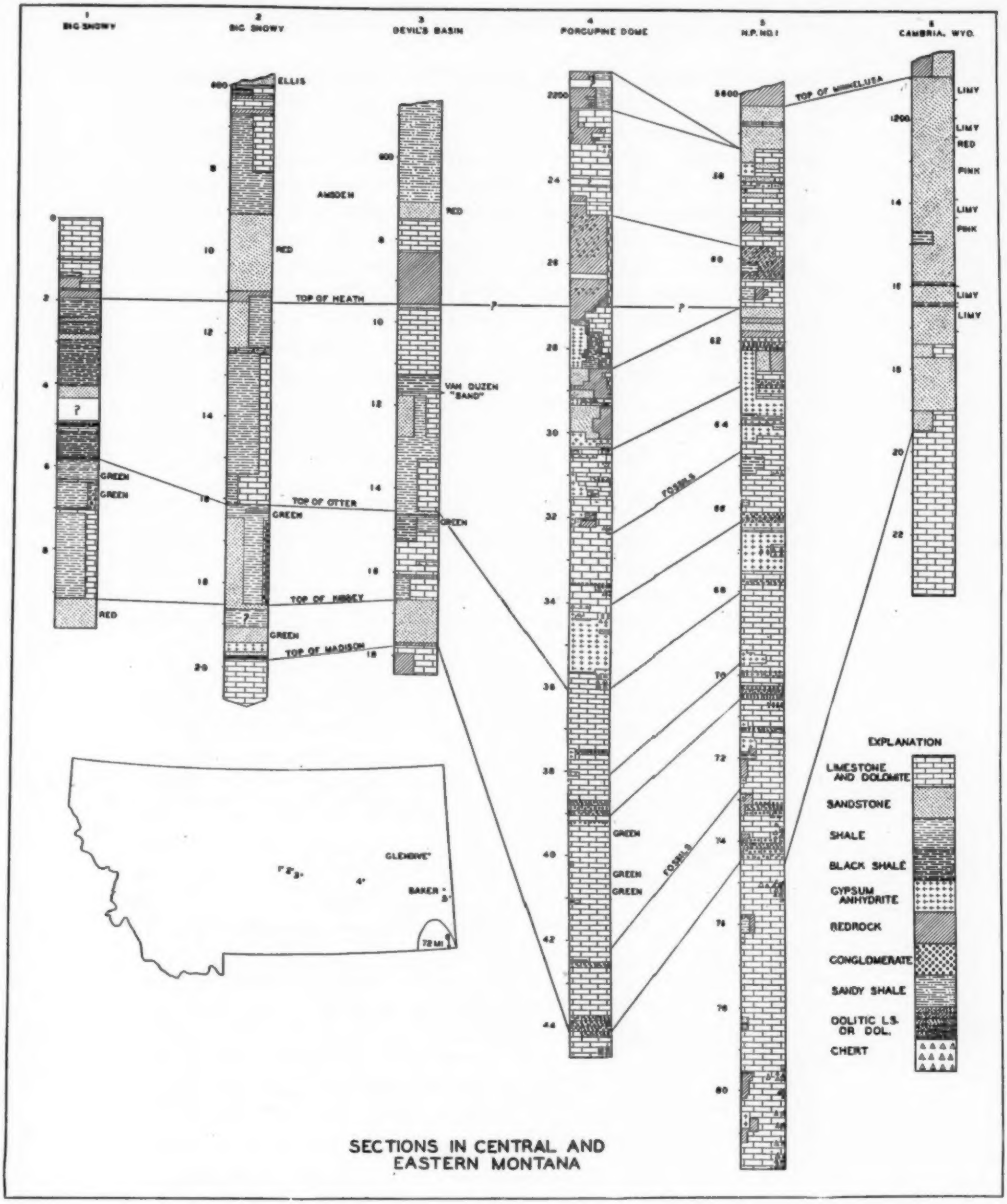
1 BIG SNOWY
2 BIG SNOWY
3 DEVIL'S BASIN
4 PORCUPINE DOME
5 N.P. NO. 1
6 CAMBRIA, WYO.
ELLIS
AMSDEN
RED
TOP OF HEATH
VAN DUZEN "SAND"
GREEN
TOP OF OTTER
TOP OF KIBBEY
TOP OF MADISON
TOP OF MINNELUSA
LIMY
PINK
FOSSILS
GLENDIVE
BAKER
72 MI
EXPLANATION
LIMESTONE AND DOLOMITE
SANDSTONE
SHALE
BLACK SHALE
GYPSUM ANHYDRITE
REDROCK
CONGLOMERATE
SANDY SHALE
OOLITIC LS. OR DOL.
CHERT
SECTIONS IN CENTRAL AND EASTERN MONTANA

FIG. 1

believed to begin with the Amsden[6] formation, which was drilled from about 5,733 to 6,115 feet. The upper two-thirds of this section is dominantly purplish to white, pink, and red dolomite and limestone, somewhat cherty, with several brecciated and conglomeratic zones. The lower one-third is calcareous to dolomitic, red, yellow, and variegated shale above, with pinkish to purplish and yellowish dolomite and limestone below. The red, yellow, and variegated shales contain several thin, fine limestone conglomerates, green shale conglomerates, and pebble conglomerates. Small limestone, dolomite, hematite, and chert pebbles and coarse grains occur sparsely throughout this shale section. The entire section is fossiliferous, and particularly the red, yellow, and variegated shales, which contain worn and rounded fossils and fragments.

A section believed closely equivalent to this was found approximately 135 miles farther north and west on the Porcupine dome (Section 4), from 2,137 to 2,700 feet. The correlation is based on stratigraphic position and a very similar lithologic character. This section is somewhat thicker than that in the Northern Pacific well, or any reported from the outcrops around the northern Big Horn Mountains. However, a decided thickening in section toward the northeast is evident in the latter area. A section measured[7] at the

[6] The Amsden formation has been classified by some authors as basal Pennsylvanian, by others Middle or Upper Mississippian. This divergence of opinion unquestionably arises from the facts that (1) the Amsden consists of two lithic zones, and (2) most rocks superjacent to the Madison and subjacent to the Quadrant or Tensleep in Wyoming have been called Amsden.

Branson and Greger have studied the Amsden of the Wind River Mountains, Wyoming, and conclude that the megascopic fauna is Mississippian, in fact as old as St. Genevieve. Morey reported on the ostracodes from the same area and concludes that the Amsden "is about St. Genevieve in age, . . . older than Chester, . . . younger than Spergen."

C. C. Branson concludes that the lower part of the Amsden is "Spergen to St. Genevieve in age, closer affinities being with the St. Genevieve," and designates this phase of the Amsden as Sacajawea. Scott recognized the Mississippian age (Chester?) of some of the Amsden in Montana, but found evidence west and southwest of Three Forks which associates the upper part of the formation with the Quadrant (Pennsylvanian).

Lee, Weed, Blackwelder, Brainerd and Keyte, C. C. Branson, and others have classified part or all of the Amsden in different sections as Pennsylvanian. A few fossils have been found in the upper part of the formation and have been identified as Pennsylvanian. However, no good faunas have been reported and therefore the conformable relationship of the overlying Quadrant is one of the main arguments for classifying the upper Amsden as Pennsylvanian. We can conclude that the Amsden contains beds of both Pennsylvanian and Mississippian age. It should also be pointed out that some zones definitely known to be as old as Middle Mississippian may not properly belong to the Amsden. A solution to the problem awaits regional studies on the post-Madison-pre-Quadrant strata.

H. W. Scott

[7] W. T. Thom, Jr., *et al.*, "Geology of Big Horn County and the Crow Indian Reservation, Montana," *U. S. Geol. Survey Bull. 856* (1935), p. 36.

mouth of the canyon of the Big Horn River is 363 feet thick. Considering this, a section 563 feet thick but 125 miles farther northeast is not surprising.

In the Big Snowy Mountains of central Montana, approximately 130 miles west of the Porcupine dome, the Amsden is about 210 feet thick (see Section 1). It is described by Scott[8] as consisting of an upper blue-gray to pink limestone 100–160 feet thick and a lower red magnesian shale or sandstone, which, in central Montana, grades into the lower part of the limestone to form a total section of about 210 feet. This shaly section in many places contains yellow, maroon, and purple beds with thin limestone-pebble conglomerates. Several of the shale beds are fossiliferous. Except for thickness, the Amsden is similar to that in sections 4 and 5. In the northern Big Horn Mountains the Amsden lacks the thick limestone at the top and contains more shale. Its description even more strongly resembles that of the beds in Section 4.[9]

In the Big Snowy Mountains and at the Porcupine dome the Amsden underlies the Ellis formation of Upper Jurassic age. In the northern Big Horn Mountains it underlies the Tensleep sandstone, believed to be of early Pennsylvanian age. In the Northern Pacific No. 1 it underlies the Minnelusa sandstone, believed to be equivalent to the Tensleep sandstone.

Based on lithology, it is considered that the Big Snowy group begins beneath the Amsden at about 6,115 feet in the Northern Pacific No. 1. At the type locality in the Big Snowy Mountains, a characteristic feature of the middle formation (Otter), according to Scott, is its oölitic nature, and at Baker this is one of the strongly characterisic features of the entire group. Another very characteristic feature of the entire group at Baker is its content, in varying amount, of thinly interbedded anhydrite. This is especially true in the upper member of the group. In central Montana the upper half of the upper member contains sandstones also. These lithologic considerations largely determine 6,115 feet as the top of the group. Below its estimated base, a fossil form, *Straparollus* sp., characteristic of the Madison limestone of Lower Mississippian age, according to A. H. Sutton, was found at 7,490–7,493 feet. On lithology, the bottom of the Big Snowy group and top of the Madison is placed at 7,440 feet. This is the base of a 45-foot section of anhydritic, extremely oölitic, cream to gray-white limestone, and the top of a thick section of pinkish gray-white to cream and light brown dolomites and dolomitic limestones.

[8] Harold W. Scott, *op. cit.*, pp. 1020, 1022, 1024.

[9] W. T. Thom, Jr., *et al.*, *op. cit.*, pp. 35–36.

The Big Snowy group in central Montana, according to Scott, is composed of an upper formation, the Heath, a middle formation, the Otter, and a lower formation, the Kibbey. In that area the group conformably underlies the Amsden formation, except in a few localities where the Amsden has been removed by erosion. It unconformably overlies the Madison limestone. While data from the wells at Porcupine and near Baker indicate the presence of strata corresponding in position and thickness to all or a substantial part of the Big Snowy group, it is impossible to identify positively the presence and the boundaries of the Heath and of the Kibbey. Prevailing fossil forms strongly resemble those which are most plentiful in the Otter. However, as stated elsewhere, a regional change in sedimentation from dominantly clastic in the west to beds of limestone and evaporite character in the east might preclude the presence of fossils of typical Heath environment in the eastern sediments. The typical Kibbey is not known to contain fossils. In spite of these considerations the possible boundaries of the three formations may be suggested.

The typical Heath formation is dominantly black shale, with three sandstone beds in the upper half and minor thin limestones throughout. Maximum thickness is about 500 feet. In the Northern Pacific No. 1 the Heath formation may have its top at 6,115 feet and consist of white to salmon-red sandstone, limestone, and dolomite, with much anhydrite and considerable dark gray, almost black shale. Limestones and dolomites from 6,400 to 6,800 feet contain much disseminated to thinly laminated carbonaceous material. Its base may be at 6,800 feet or may be marked by scolecodonts at 6,762–6,766 feet, or may even be as high as 6,514 feet, where a *Productus*-bearing limestone begins. H. W. Scott favors this bed for the top of the Otter.[10] At 6,747 feet oil production was obtained.

In the Big Snowy Mountains the Otter formation underlies the Heath conformably and is composed of green to gray shales with thin oölitic and fossiliferous limestones, 300–350 feet in total thickness. In the Northern Pacific No. 1 its base is uncertain. It may be at about 7,165 feet where considerable red to maroon shale and red to maroon coloration of the limestone and dolomite comes into the section. The red material may be indicative of the underlying Kibbey formation. If 7,165 feet is the base and 6,800 the top of the Otter, then it is 365 feet thick and is principally limestone and dolomite but contains much anhydrite. The limestones are commonly oölitic.

In the Big Snowy Mountain region the Kibbey formation under-

[10] Harold W. Scott, University of Illinois (personal communication).

lies the Otter conformably, and is composed of about 120 feet of calcareous, red, non-fossiliferous, shaly sandstone, with lenses of gypsum as much as 30 feet thick. In the Northern Pacific No. 1 the section extending from 7,165 to 7,440 feet consists of very fossiliferous, shaly, reddish gray, rather mottled, to gray-white, dolomitic limestone. It is anhydritic (particularly in the upper part), with thinly interbedded red to maroon and some light gray shales, to 7,385 feet, and with non-fossiliferous, extremely oölitic, gray-white limestone to 7,440 feet. Presence of the anhydrite and red shale merely suggests the Kibbey age of this section. No adequate evidence is available. Since the Heath, Otter, and Kibbey are a closely related group of formations, and the upper two appear to change from clastic to less clastic beds between their outcrops in central Montana and Baker, it seems possible that this condition may hold also for the Kibbey, and give conditions favorable for the abundant marine life evident in the Northern Pacific No. 1 section herein suggested to be of Kibbey age.

The apparent thickness of the Big Snowy group in the Northern Pacific well No. 1 is 1,325 feet, which compares favorably with a maximum thickness in central Montana of 1,200 feet. Age of the beds at Baker as Mississippian, and correlation with the group as a whole in central Montana are considered fairly well established by the accompanying list of fossils, even though there are marked variations in lithologic character. Separation of the group into its typical formations is only suggested.

At least a considerable part of the group, if not all, is believed to be present on the Porcupine dome. Determinative fossils have not been found, although there seems to be a close resemblance in the fauna, as listed by Sutton on a later page. On the basis of considerable black shale and anhydrite in the Porcupine section, as at Baker, it is suggested that the Heath formation is present from about 2,700 to about 3,620 feet. The Big Snowy group probably extends to 4,450 feet. Below 3,035 feet the limestones are very commonly oölitic. Traces of green shale appeared at approximately 3,900, 4,000, and 4,040 feet. Zones of fossils occurring in this section and that of the Northern Pacific No. 1 are mentioned by Sutton on a later page. A disturbing feature is the extreme thickness, 1,750 feet, for the beds between the Amsden and the Madison, to which the name Big Snowy group is applied. It is not known elsewhere to exceed approximately 1,200 feet, or 1,325 feet at Baker, as previously described. Many detailed lithologic similarities exist between the sections at Porcupine and Baker at horizons which will not be described but which are indicated by correlation lines in Figure 1.

MADISON LIMESTONE

As previously stated, the Madison limestone was topped at 7,440 feet in the Northern Pacific No. 1 as determined by faunal and lithologic evidence. Extending from 7,440 to 7,955 feet is a section of crystalline, white, grayish white, brownish, pinkish, and light purplish, sparsely fossiliferous dolomite. It is calcareous from 7,440 to 7,540 feet; shaly (maroon to purplish and light-colored) from 7,575 to 7,620 feet; and somewhat cherty, at intervals, from 7,500 to 7,620 feet and from 7,940 to 7,955 feet. Lithologically this section closely resembles the Pahasapa limestone of the Black Hills, which is also of about the same thickness. The section from 7,955 to 8,055 feet, consisting of whitish to purplish, finely crystalline, shaly to silty dolomite; maroon to purple shale; and finely crystalline, gray-white to purplish dolomite, may be equivalent to the Englewood of the Black Hills, which it closely resembles. The entire section from 7,440 to 8,055 feet is probably equivalent to the Madison limestone, Lower Mississippian, of areas west and southwest. The very few fossils recovered which are believed to be Madison forms are listed on a later page.

LOWER FORMATIONS

The section from 8,055 to 8,130 feet is gray-white to maroon, reddish, and purplish dolomite and limestone, fossiliferous, with much gypsum to 8,090 feet, much maroon to red shale to 8,125 feet, and reddish gray limestone to 8,130 feet. The section from 8,130 to 8,186 feet is oil-saturated, finely crystalline, finely porous, brown dolomite with some fossiliferous, purplish gray, dolomitic limestone from 8,140 to 8,155 feet, and with traces of chert from 8,160 to 8,186 feet. From information available these beds may be of Upper Devonian, Three Forks age. No fossils were identified.

FOSSILS FROM NORTHERN PACIFIC WELL NO. 1 AND WESTPHAL PERMIT WELL

The following list and statements are kindly contributed by A. H. Sutton.[11]

Cuttings and cores from the N.P. No. 1 well and the Westphal No. 1 well yielded considerable evidence of the Mississippian age of certain beds, but the macro-fossils were, in most instances, so fragmental as to render specific identification impossible, and the micro-fossils of this part of the country are not sufficiently known to make them of great value for detailed correlation. Identification of the ostracodes has been kindly checked by Dr. H. W. Scott. Although I examined cuttings from some of the younger horizons, my work was

[11] A. H. Sutton, University of Illinois, Urbana, Illinois.

chiefly on the Carboniferous rocks, and the following remarks pertain to those strata. The following fossil forms have been identified with some degree of certainty.

FOSSILS FROM THE NORTHERN PACIFIC WELL NO. 1

Depth in Feet	
5,997–6,000	*Chonetes granulifer* (?). *Dictyoclostus*
6,105–6,110*	*Equisetales* fragment
6,180–6,188	*Equisetales* fragment
6,188–6,193	*Rhombopora* sp.
6,193–6,198	*Rhombopora* sp.
6,420–6,423	Fragments of *Deltopecten* sp., *Spirifer* sp., *Allorisma* sp.
6,427–6,432	*Lingula* sp.
6,467–6,468	*Orthotetinae*, *Camarotoechia* sp., *Spirifer* sp., *Dictyoclostus* sp.
6,472–6,477	Several fragments of some *Orthotetinae*
6,496–6,504	*Pustula* sp.
6,528–6,546	*Composita* sp., *Eumetria* sp., *Paraparchites* cf. *nicklesi* and many fragments of some *Orthotetinae*
6,546–6,564	*Punctospirifer* cf. *transversa*. Productid fragments
6,610–6,628	*Orthotetinae*
6,646–6,662	*Paraparchites* sp.
6,672–6,678	*Paraparchites* cf. *nicklesi*
6,743–6,747*	*Bairdia* sp. or *Cytherella* sp.
6,762–6,766	Scolecodont
6,768–6,778	*Chaetetes* sp., *Productidae*, *Orthotetinae*
6,768–6,788	Tabulipora
6,910–6,917	*Streblotrypa* cf. *nicklesi*
6,917–6,920	*Cypricardella* (?) sp.
7,104–7,107	Fenestellid bryozoan
7,180–7,185	Ostracode fragment, possibly *Bairdia*
7,190–7,195	Scaphopod (Dentalium)
7,195–7,285	Fragments of *Spirifer*, *Punctospirifer*, *Composita*, and various *Productidae*
7,285–7,390	Fragments of various brachiopods; *Rhipidomella* or *Schizophoria* and *Schuchertella*, *Schellwienella* or *Streptorhynchus*. Also *Spirifer*, *Productidae* and *Chonetidae*
7,490–7,493	*Straparollus* sp.
7,680–7,683	*Euomphalus* sp.
7,910–7,915	*Rhombopora* sp.
7,953–7,965	Fragments of *Schizophoria* and *Schuchertella*
7,995–7,999	Fragments of *Chonetes*

* Fossils from 6,105 to 6,198 and 6,743 to 6,747 feet were obtained from cuttings that may be inaccurately located as to depth.

The first of the above listed specimens, between 5,997 and 6,198 feet in depth, are forms which appear Pennsylvanian in aspect but may be of late Mississippian age. The *Orthotetinae* which occur through a considerable thickness of strata can not be identified, even generically, with certainty, because of the fragmental and flattened nature of the specimens, which masks details of cardinal area and internal structures. The ostracode, *Paraparchites* cf. *nicklesi*, appears to be closely related to that common species of the Moorefield formation in Arkansas. It is also similar to some of the Salem forms of the Mississippi Valley region. The scolecodont, 6,762 to 6,766 feet in depth, is much like those which are known in outcrop from only the lower portion of the Heath formation of the Big Snowy group farther west in Montana. However, above this in the well are productid fragments which may possibly represent an upper Otter horizon. *Tabulipora* sp., 6,768–6,788, is similar to a

species which is abundant in the middle portion of the Chester series in the Mississippi Valley area. *Cypricardella* sp., 6,917–6,920, is similar to the forms which are more or less common in the Brazer formation farther west. Scaphopods like the one from 7,190–7,195 have been reported from the Brazer but not from the Madison formation.

On the basis of available fossil evidence and lithologic character of the rocks I have assigned the following limits to the Mississippian strata in the well. The top of the undoubted Mississippian is possibly as low as 6,420 feet. I have no definite evidence on which to divide the upper portion of the Mississippian as between Amsden and Big Snowy, or into formations of the Big Snowy group, although the scolecodont at 6,762 feet suggests the lower portion of the Heath. *Straporollus* sp., 7,490–7,493, and *Euomphalus* sp., 7,680–7,683, are Madison forms. The top of the Madison has been placed at about 7,440 feet depth, chiefly on the changes in lithology at that depth. The bottom of the Mississippian is placed at approximately 8,060 feet. The lowest 100 feet or so of the Mississippian is lithologically like the reported Englewood of the Black Hills section.

Evidently there is a thick section of post-Madison Mississippian rocks which may well be equivalent to the Big Snowy group. The most significant fossils are entirely consistent with such a correlation.

The rock below 8,060 feet is lithologically similar to the Devonian (Three Forks formation) exposed in western Montana. This opinion is concurred in by Dr. H. W. Scott, who has seen many exposures of the Three Forks formation. I have no positive paleontological evidence to support a Devonian age for these beds, although the fragmental fossil remains are of forms which are not older than Devonian.

FOSSILS FROM WESTPHAL WELL NO. 1

Depth in Feet	
2,565–2,575	*Sansabella* (?) sp.
2,700–2,710	*Bairdia* sp.
2,710–2,720	Ostracoda, indeterminate
2,840–2,845	*Fistulipora* sp., *Composita* sp.
3,205–3,215	*Sansabella* sp.
3,220–3,230	*Spirorbis* sp.
3,245–3,246	*Camarotoechia* sp., *Syringopora* sp.
3,246–3,251	*Orthotetinae*
3,286	*Productidae*
3,288	*Camarotoechia* sp., *Orthotetinae*
3,680	Fenestellid bryozoan, *Orthotetinae*, *Nucula* (?) sp., *Spirifer* sp.
3,800–3,810	*Composita* sp.
3,931–3,936	*Orthotetinae*, *Spirifer* sp.
3,960–3,970	*Bairdia* sp., *Paraparchites* sp.
4,124–4,130	*Camarotoechia* sp.
4,190–4,200	*Paraparchites* sp.
4,210–4,220	*Camarotoechia* sp.
4,250–4,270	*Orthotetinae*
4,350–4,360	*Camarotoechia* sp.
4,490–4,501	*Camarotoechia* sp., *Leptaena* sp.

All of the above identified forms are of Carboniferous age. *Sansabella* sp., 3,205–3,215, according to H. W. Scott, is conspecific with an undescribed form from the Otter formation. *Spirorbis* sp., 3,220–3,230, is very similar to a species reported by C. C. Branson from the Sacajawea formation of Wyoming. The specimens of *Paraparchites* and *Camarotoechia* reported from several

horizons in the wells are forms which are more abundant in the Otter than in any other formations in outcrop. Only one species of *Paraparchites* has been reported from the United States in beds which are definitely known to be older than Warsaw. This is a middle Devonian species.

A correlation of the two zones of abundant *Orthotetinae*, from 3,246 to 3,288 feet and from 4,250 to 4,270 feet in the Prairie well with the two in the N.P. No. 1 well, from 6,472 to 6,477 and 7,285 to 7,390 feet, would not be unreasonable. If the lower zone in the two wells is the same, the top of the Madison in the Prairie well would probably be below 4,270 feet in depth. The evidence of *Paraparchites* supports a post-Madison age for the beds above that horizon. *Leptaena* sp., 4,490–4,501, probably indicates a horizon in the Madison no younger than Burlington. I know of no reported occurrence of *Leptaena* in Mississippian strata younger than the Burlington.

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GEOLOGY OF WIND RIVER CANYON, WYOMING[1]

C. T. JONES[2]
Casper, Wyoming

ABSTRACT

The Wind River Canyon is in Fremont and Hot Springs counties, central Wyoming, and constitutes one of the many scenic areas of the Rocky Mountain region. The canyon was formed by the Wind River cutting through the Bridger-Owl Creek Range. It has a length of 15 miles and reaches a depth in places of half a mile. Exceptional opportunity is offered the geologist to study the stratigraphy and structure because of the great number of outcrops and the great relief. Rocks ranging from pre-Cambrian to Eocene in age are exposed in the canyon and its vicinity. The part that faulting plays in mountain building is exceptionally well shown, and much evidence bearing on the controversy, whether or not most of the ranges of the region are vertical uplifts or ramp structures, is obtainable. The Bridger-Owl Creek Range is an east-west trending asymmetrical anticline which has undergone much faulting on the south flank. Both normal and reverse faults are present, and the fault at the south portal is low in angle. This thrust developed during uplifting after it became easier for the strata to move on a thrust plane rather than to be uplifted further. As the force was still being applied the axis rotated toward the horizontal until the crestal area became totally unsupported. It then broke free resulting in the large normal fault at Boysen Dam. Uneven settling of this block produced the wedges bounded by normal and reverse faults.

INTRODUCTION

The Wind River Canyon is in Hot Springs and Fremont counties, central Wyoming, and mostly within Ts. 5 and 6 N., R. 6 E., Wind River Meridian. The canyon was formed by the Wind River, or Bighorn River as it is known farther downstream, intrenching the Bridger-Owl Creek Range which separates the Wind River and Bighorn structural and topographic basins.

Between the north and south portals of the canyon may be found 15 miles of scenic interest and, to the geologist, a continuous panorama of structural and stratigraphic exposures. The northward-flowing river is generally confined to a narrow sheer gorge which in some places reaches a depth of half a mile.

The work was undertaken primarily to establish, if possible, the type of faulting associated with uplift. Due to the unlimited exposures it was believed that an accurate solution was obtainable; these data could then be applied in the study of other Rocky Mountain uplifts where outcrops were not so conclusive.

Some geologists have cited the asymmetrical Bridger-Owl Creek Range and the near-by asymmetrical anticlines of the Bighorn Basin as examples of the type of features which are found in "foreland" and

[1] Published by permission of Stanolind Oil and Gas Company, Tulsa, Oklahoma. Manuscript received, January 3, 1939.

[2] Geologist. Box 40.

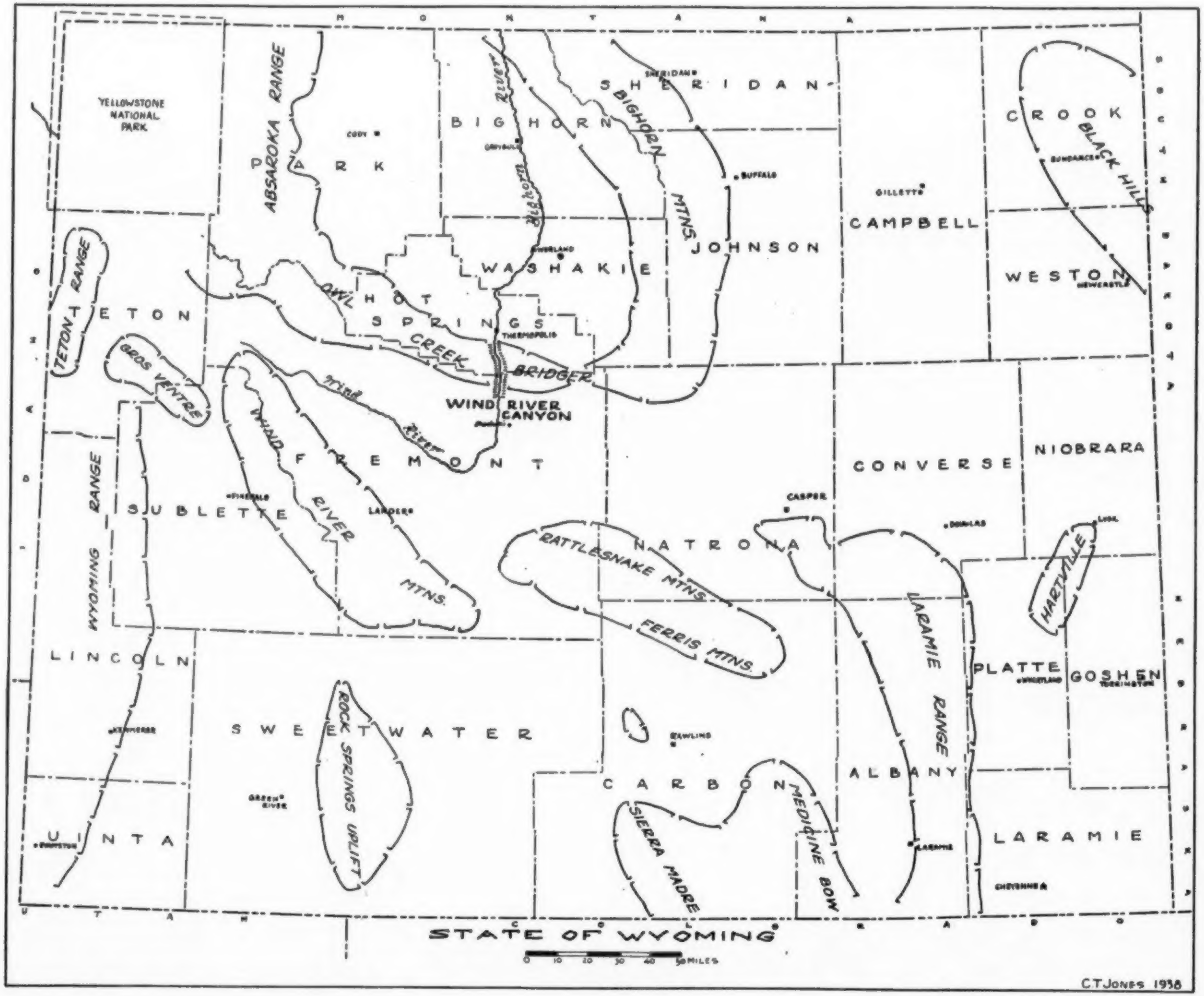


FIG. 1.—Index map.

"shield" areas throughout the world.[3] Considered as other examples are the tilted crustal blocks purported to underlie the Mid-Continent uplifts which have defined the Cushing, Garber, and Oklahoma City oil pools; the faulted uplifts which have controlled mineralization and ore deposition in parts of the southern Rockies; and the "ramp" uplifts which border the "rift valleys" of Africa and Palestine which Willis[4] explains as ramp structures.

A ramp structure may be defined as a tilted crustal block broken on one side by a steep fault plane which, as it extends in and under the tilted block, becomes flatter in dip. A sled might be used to illustrate —the sled itself is the ramp structure, and the anterior edge of the sled runner is the fault plane—steep near the top but flattening as the runner passes under the sled.

The Bighorn Basin-Yellowstone Valley Tectonics Field Conference[5] held in August, 1937, was presented with the general problem of the nature and origin of such structural features, and it was hoped to demonstrate from readily visible exposures in parts of the Bighorn Basin and Yellowstone Valley that, among other things:

> asymmetrical anticlines pass by imperceptible gradation into "tilted fault blocks"—which, at first, are bordered by visible "normal" faults along their steep sides, and then change over into "low angle overthrusts," usually with one or two subsidiary thrust slices in front of them.

Some of the sponsors of the conference proposed to use the structure of the Wind River Canyon as support for this theory. However, as doubt was expressed by others in attendance that the data alone supported such a hypothesis, it was decided that further surface work would add information which would aid in the solution of this controversy. It might therefore be said that this work is a result of the conference.

It is hoped that this brief discussion will in no way detract from the greater value and importance of a paper now in preparation by J. R. Fanshawe covering the tectonics of the adjoining Bridger-Owl Creek Range. It is understood that this work is of a very detailed nature and has been in the process of completion for some time. Undoubtedly, when published, it will not only present a thorough picture

[3] The data contained in this paragraph are generally from the following text: *Guide Book, Bighorn Basin-Yellowstone Valley Tectonics Field Conference* (August 3–5, 1937), Rocky Mountain Assoc. of Petrol Geol., and Yellowstone-Bighorn Research Assoc., in coöperation with Montana Bureau of Mines and Geology, Wyoming Geological Survey and National Park Service.

[4] Bailey Willis, "Dead Sea Problem: Rift Valley or Ramp Valley?" *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 490–542.

[5] *Guide Book, op. cit.*

of the geology of the Wind River Canyon but will also give comparisons of its structure with that of adjoining areas.

However, as the Wind River Canyon in itself constitutes a major attraction to the tourist and geographer, it was decided to publish the present paper, especially since so little reference has been made to the area in the past.

FIG. 2.—View downstream into canyon from south portal.

This work was done under the direction of John G. Bartram, who offered many valuable suggestions and criticisms. To him is given much of the credit for the plausible explanation of the many controversial structural features mapped in the field. Also, the detailed section herewith presented, of Mesozoic strata cropping out near the town of Thermopolis, was measured by him and J. E. Hupp. Sincere appreciation is expressed to C. W. Tomlinson for reading and criticizing the manuscript.

STRATIGRAPHY

Within the canyon proper, the exposed formations range from pre-Cambrian to Eocene in age. The pre-Cambrian consists of dark dioritic rocks whose prominent schistosity at Boysen Dam dips 60° S. The rocks have been intruded by irregular masses, generally somewhat horizontal or slightly inclined, of red granite containing large quantities of white quartz in veins.

Gwynne[6] reports that the schistosity of the pre-Cambrian rocks generally decreases from 60° to 30° northward from Boysen Dam and

[6] C. S. Gwynne, "Granite in the Wind River Canyon, Wyoming," *Bull. Geol. Soc. America*, Vol. 49 (1938).

that the amount of intrusive granite and pegmatite increases in the same direction.

Overlying the pre-Cambrian strata with somewhat of an undulating contact is the Deadwood formation,[7] consisting of several lithologic units. It is 1,105 feet in thickness and is considered Middle and Upper Cambrian in age.

FIG. 3.—Pre-Cambrian rocks in central part of canyon.

The basal member, known as the Flathead sandstone, consists of brown laminated sandstone, coarse and arkosic at the base, and some thin intercalations of greenish shale. The sandstones are locally indurated into quartzite. This unit has a thickness of approximately 200 feet and grades upward into the next member, which has a thickness of 210 feet, consisting mostly of reddish brown fissile micaceous shales and sandy shales with a few greenish gray shale and sandy shale intercalations. This member is capped by a prominent bed of reddish brown sandy shale which forms a distinct band of color in the lower canyon walls.

The conformable overlying member consists of 180 feet of slightly micaceous greenish gray laminated glauconitic shales, sandy shales, thin limestones, and a few beds of edgewise or flat pebble intraformational conglomerate. A few intercalations of reddish brown shale and sandy shale are present.

Next, a cliff-forming, buff, thin-bedded limestone, 80–100 feet in thickness, occurs. This forms a prominent bench in the canyon below the walls of Bighorn and Madison strata.

[7] N. H. Darton, "Geology of the Bighorn Mountains," *U. S. Geol. Survey Prof. Paper 51* (1906).

TABLE I

GENERALIZED COLUMNAR SECTION

Age	*Formation*	*Thickness in Feet*	*Description*
Eocene	Wasatch	—	Variegated clays, and coarse sandstones
Cretaceous	Mowry-Thermopolis	—	Siliceous and black shale with Muddy sandstone 182 feet above base
	Cloverly	195	Dark and variegated shale, sandstone —conglomeratic at base
Jurassic	Morrison	261	Variegated shale and sandstone
	Sundance	490	Variegated shale, sandstone, limestone, and gypsum
Triassic	Jelm	252	Red sandstone and shale
	Chugwater	820	Red sandy shale with Alcova limestone at top
	Dinwoody	55	Gypsum and yellow shale
Permian	Phosphoria	220	Limestone and shale
Pennsylvanian	Tensleep	270	Sandstone
Pennsylvanian (?)	Amsden	280	Red sandstone and shale, limestone
Mississippian	Madison	530	Cherty limestone
Ordovician	Bighorn	50	Dolomite
Cambrian	Deadwood	1,015	Limestone, shale, and basal Flathead sandstone
Pre-Cambrian		—	Dioritic schists, granites

The overlying strata, 325 feet in thickness, making up the balance of the Deadwood formation, consist of micaceous greenish gray shales, thin gray laminated limestones, and many thin beds of intraformational conglomerate. There appears to be a greater quantity of shale in the lower part of this unit; near the top the beds become predominantly reddish in color.

Deiss[8] has recently applied the names Depass and Boysen to these Cambrian strata in Wind River Canyon. His basal Depass formation contains the Flathead sandstone member at the base and the overlying Gros Ventre member. These members include the basal Flathead sandstone, the overlying 210 feet of predominant reddish brown shale and sandy shale, and a part of the overlying 180 feet of greenish gray shales, sandy shales, and limestones as described in this article. His boundary of Middle and Upper Cambrian rocks is not marked by a lithologic change. He divides the Upper Cambrian into three members: the basal Maurice, the medial Snowy Range, and the upper Grove Creek member. The 80–100 feet of cliff-forming limestone as described herein is at the top of his Maurice member. The overlying 325 feet of strata are the equivalent of his Snowy Range and Grove Creek members.

Condit,[9] in describing the Cambrian of the Wind River Mountains,

[8] Charles Deiss, "Cambrian Formations and Sections in Part of Cordilleran Trough," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 1067–68.

[9] D. Dale Condit, "Phosphate Deposits in the Wind River Mountains, near Lander, Wyoming," *U. S. Geol. Survey Bull. 764* (1924).

uses the names, Flathead, Gros Ventre, and Gallatin formations. The Flathead member of his section is the same as the one described herein. His Gros Ventre member probably includes the predominant shale section up to the base of the 80–100 feet of cliff-forming limestone, and the Gallatin includes this limestone and the balance of the Cambrian section.

The main cliff-forming formations then occur, the lower Bighorn dolomite and the overlying Madison limestone, totaling 580 feet in thickness. Although a hiatus exists between these formations, one appears to grade into the other lithologically, and considerable difficulty is experienced in determining the actual contact. A tentative thickness of 50 feet[10] is assigned to the Bighorn dolomite and 530 feet to the Mississippian Madison limestone.

The Bighorn dolomite consists of buff massive strata containing irregular reticulations of siliceous material on its weathered surfaces. The basal part of the Madison limestone is made up of buff, bedded, cherty limestone; the upper part is lighter and grayer, purer in calcareous content, and commonly weathers into castellated forms.

The Amsden formation of Pennsylvanian (?) age, having a thickness of 280 feet, conformably overlies the Madison limestone and consists of a brownish gray slabby cross-bedded sandstone at the base, red shales containing thin pinkish limestones, and an upper part of sandstones, cherty at the top and reddish in color.

Conformably, the Tensleep sandstone next occurs. It is 270 feet thick, crops out as an upper cliff in the walls of the canyon, and consists of cross-bedded, cream to buff-colored, fine to medium-grained sandstone, locally quartzitic and indurated.

Overlying are strata known to some as Embar[11] but subdivided in this paper into the Phosphoria formation below and the Dinwoody formation above.[12] The Phosphoria formation of Permian age caps the prominent, denuded north-dip slope of the Bridger-Owl Creek Range which is so well observed from the vicinity of the town of Thermopolis. It consists of a thin gray limestone at the base, grading upward into a series of grayish brown calcareous phosphatic shales and limestones which contain nodules and lenses of chert especially near the top. This section is 220 feet thick and is overlain by the Dinwoody formation, probably Triassic in age, consisting of 55 feet of strata with a basal yellow shale 30 feet in thickness and an upper 25 feet of white massive gypsum.

[10] N. H. Darton, *op. cit.*

[11] N. H. Darton, *op. cit.*

[12] D. Dale Condit, *op. cit.*

Since the succeeding formations from the Triassic Chugwater to the Upper Cretaceous Mowry-Thermopolis do not crop out in the canyon in their entirety, being faulted out in part at the south portal, they are described from their outcrop north of the canyon in the vicinity of Thermopolis.

Age	*Formation*	*Description*	*Thickness in Feet*	*Formation Thickness*
Cretaceous	Mowry-Thermopolis	Siliceous shale and black shale containing 20 feet Muddy sandstone 182 feet above base		
	Cloverly group (contains equivalents of Dakota sandstone, Fuson shale, and Lakota sandstone)	Brown thin-bedded sandstone	2	
		Dark blue shale	3	
		Brown platy sandstone	5	
		Dark shale	20	
		Brown sandstone	2	
		Dark shale—few thin sandstones	24	
		Black ferruginous sandstone	2	
		Dark shale	22	
		Brown to yellow ferruginous sandstone, weathers to 6-inch slabs	15	
		Dark gray and blue shale	15	
		Gray green sandstone	4	
		Yellow and white sandstone	2	
		White shale	7	
		White sandstone	3	
		Pink and white shale	14	
		Gray pink sandstone	3	
		Gray pink shale	7	
		Massive cliff-making white to buff sandstone. Base conglomeratic	45	195
Jurassic	Morrison	Gray and red clay shale	108	
		Creamy white soft sandstone slightly pink near base	153	261
	Sundance	Greenish gray sandstone	5	
		Greenish gray sandy shale, some thin sandstones	12	
		Greenish gray laminated sandstone	40	
		Greenish gray shale and sandy shale	22	
		Fossiliferous gray limestone	3	
		Fossiliferous sandy limestone and shale	8	
		Soft greenish gray shale	40	
		Gray fossiliferous limestone	2	
		Shale	3	
		Gray fossiliferous limestone	3	
		Greenish gray shale—belemnites	30	
		Gray brown sandstone	2	
		Gray shale—thin pink sandstone at top	40	
		Blocky buff sandstone—calcareous at top	5	
		Light gray sandy shale	10	
		Soft creamy sandstone	14	
		Gray shale	27	
		Oölitic platy sandy limestone	12	
		White crossbedded sandstone	4	
		Gray shale	5	

Age	Formation	Description	Thickness in Feet	Formation Thickness
Jurassic (*Cont.*)	Sundance (*Cont.*)			
		Red shale	11	
		Hard pinkish white shale	2	
		Red shale	2	
		Hard white shale	5	
		Gypsum	5	
		Red shale	3	
		Gray dolomitic limestone	4	
		Red shale	21	
		Mixed red shale and gypsum	42	
		White gypsum	55	
		Soft red sandstone	53	490
Triassic	Jelm	Red sandy shale—some red sandstone	137	
		Soft pinkish white sandstone	23	
		Red sandy shale—some white sandstone	27	
		White sandstone	4	
		Red sandstone	8	
		Red and gray sandstone	16	
		Buff sandstone	37	252
	Alcova limestone	Blue gray to purple limestone	2	2
	Chugwater	Bright red sandstone	53	
		Red shale and red sandy shale to top of Dinwoody	765	818

Just south of the southerly fault in the canyon the Eocene Wasatch formation, consisting of buff to gray massive coarse sandstones and gray and red clay shales, overlaps beds of Mowry-Thermopolis age with pronounced angularity.

STRUCTURE

The Bridger-Owl Creek Range is an east-west trending asymmetrical anticline, the south flank of which has been considerably broken in Wind River Canyon by six large and two relatively minor faults. The gentle north flank dips regularly 4° N.

Commencing from the north, the first fault, which is located at Boysen Dam and which is called the secondary fault in this paper, is normal in type and dips south approximately 65°. Upper Cambrian shales are downthrown against pre-Cambrian rocks; the vertical displacement is approximately 1,500 feet. Of interest is the fact that the schistosity of the pre-Cambrian rocks is almost parallel with the dip of the fault plane.

A small normal fault next occurs which is downthrown on the south side. The plane dips about 65° S., and the vertical displacement is almost 100 feet.

FIG. 4.—View of east side of canyon showing normal fault at Boysen Dam.

FIG. 5.—View of west side of canyon showing reverse fault (fifth fault of discussion).

The area between the secondary normal fault at Boysen Dam, and the next major fault on the south, in which this second minor fault is located, is a graben. The third fault, which bounds this graben on the

south, is also normal in type but, conversely, dips 60° N. It is downthrown on the north and has a vertical displacement of almost 410 feet.

The fourth fault is the first reverse fault and bounds a horst on the south consisting mainly of pre-Cambrian rocks. This fault dips at a rate of about 60° N. and has approximately 500 feet of vertical displacement. The outcrop of these resistant pre-Cambrian rocks has so narrowed the canyon that the railroad has had to tunnel through some of the upthrown block.

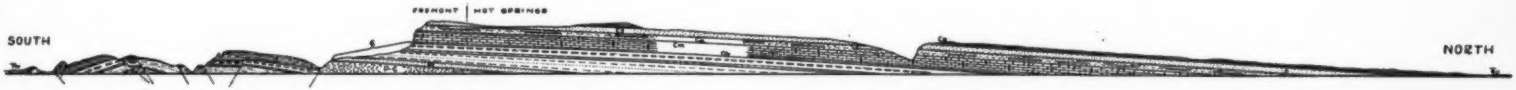
The fifth fault is also reverse in type, dips about 57° N. and bounds a second graben on the north. This fault has about 300 feet of vertical displacement.

On the south side of this graben the sixth fault occurs. This is normal is type and dips north at a slightly lower angle. Its vertical displacement is approximately 350 feet. The south upthrown side has again brought up pre-Cambrian rocks in the bottom of the canyon which have caused the railroad to tunnel. South of the sixth fault the strata have for the first time assumed a normal south dip on the south flank of the range.

Lastly, the seventh and eighth faults occur. The seventh is a small normal fault which bounds a wedge of Madison limestone on the upthrown limb of the eighth or overthrust fault. This thrust is perhaps the most interesting structural feature of the canyon. Considerable crumpling of strata is present on the downthrown side which resulted from the movement of the heavy Paleozoic strata over the younger less resistant Mesozoic strata.

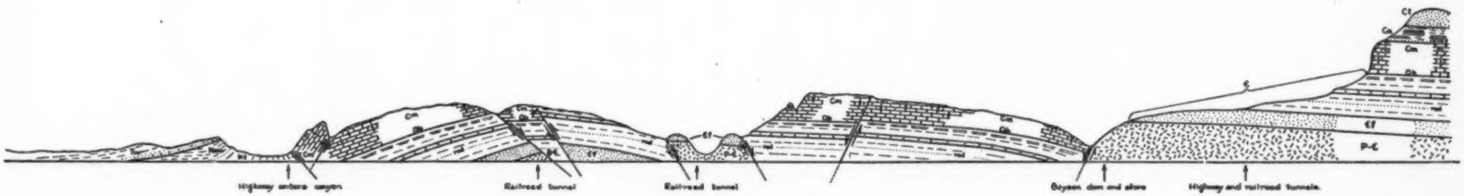
This thrust fault, referred to in this discussion as the primary fault, dips north and has a vertical displacement, based on thicknesses of strata measured near Thermopolis, of 2,800 feet. However, the amount of displacement varies considerably along the trace of the fault plane; for instance, on the west bank of Wind River the contacting formations are the Thermopolis shale and the Madison limestone. Less than half a mile farther west the Lakota sandstone member of the Cloverly formation is in juxtaposition with the Tensleep sandstone; the amount of vertical displacement has therefore decreased toward the west. On the east side of Wind River in the railroad cut, as Dinwoody gypsum is in contact with Cambrian green shales, the amount of vertical displacement has decreased.

The dip of the thrust plane approximates 50°, which is somewhat less than the dips of the other reverse faults on the north; however, landsliding of large masses of heavy resistant Paleozoic strata may



Structure of Wind River Canyon
as observed from highway.

miles



Detail of South End of Wind River Canyon

miles

EXPLANATION

Eocene	Wasatch fm.	Tw	—
Cretaceous	Mowry-Thermopolis	Kmr & Kt	—
	Cloverly fm.	Kcv	195'
	Dakota ss.		
	Fuson sh.		
	Lakota ss.		
Jurassic	Morrison fm.	Jm	261'
	Sundance fm.	Js	490'
Triassic	Jelm fm.		252'
	Chugwater fm.		820'
	Dinwoody fm.		55'

Permian	Phosphoria fm.	Cp	220'
Pennsylvanian	Tensleep ss.	Ct	270'
	Amsden fm.	Ca	280'
Mississippian	Madison ls.	Cm	580'
Ordovician	Bighorn ls.	Ob	
Cambrian	Deadwood fm.	€	1015'
	Flathead ss at base.	€f	
Pre-Cambrian	Diorites, granites.	P€	—

C.T. Jones November 1938.

FIG. 6

have obscured much of the true structural relationship along the thrust plane, tending to make it appear flatter than it actually is.[13]

STRUCTURAL HISTORY

Middle Cambrian to Upper Cretaceous sediments exposed in the vicinity of Wind River Canyon disclose evidence of several periods of emergence and erosion, but no angularity in unconformity is shown. The upfolding of the Bridger-Owl Creek Range commenced at the close of the Cretaceous during the so-called Laramide revolution, which formed the other mountain ranges of the Rocky Mountain region. The uplifting of those ranges resulted from continuing horizontal pressure apparently applied in general from the southwest which, due to differences in the competence of strata or its application at different levels, produced the lack of symmetry so noticeable in structures of the region.[14]

Once that asymmetry was operative it easily became accentuated and the south or steep limb of the range became steeper and narrower until it actually was vertical or slightly overturned. It was then that the strata commenced to fracture and move on a thrust plane which was a much easier process to accomplish than further uplift. Thus was formed the primary fault.

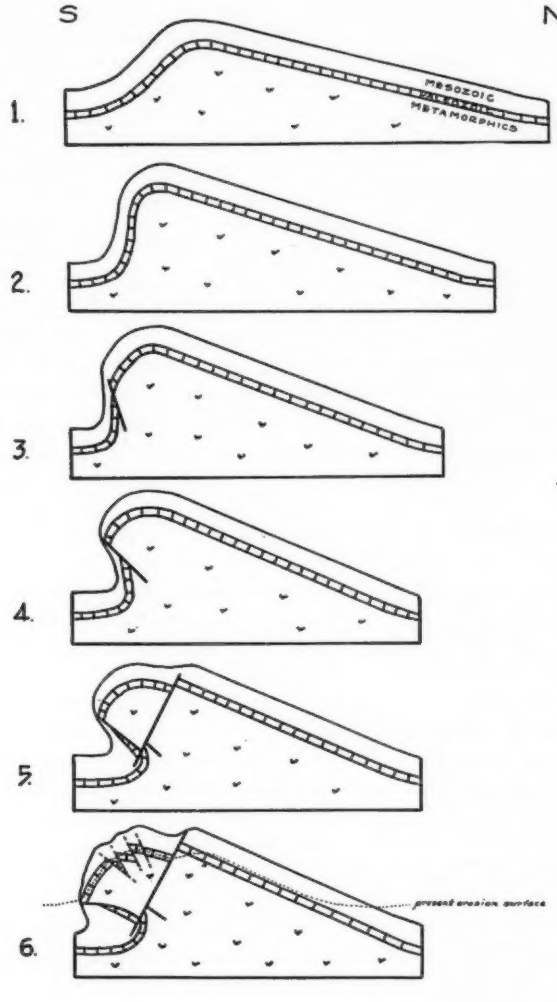
As uplifting continued the crest of the anticline moved over the steep and largely unsupported south limb. The crestal area ultimately reached a totally unsupported position causing it to break loose from the main mass of the fold and slide downward. Thus the secondary normal fault at Boysen Dam was formed. Uneven settling of this block of strata produced local conditions of either tension or compression, resulting in the formation of the other normal and reverse faults.

Subsequent erosion left heavy Paleozoic strata many hundreds of feet higher topographically than the area of outcrop of the less resistant Mesozoic strata. As these blocks of heavy Paleozoic strata became unsupported through further erosion, they slid into their present positions, further complicating the structural relationships along the primary thrust.

Later, during Eocene Wasatch deposition the range was still being uplifted because Wasatch beds show a slight increase in rate of dip where they overlap older facies.

[13] The importance of landsliding is ably discussed by C. W. Tomlinson in an unpublished manuscript, "Notes on the Bighorn Basin-Yellowstone Valley Tectonics Field Conference, August 3–5, 1937."

[14] John G. Bartram and J. E. Hupp, "Subsurface Structure of Some Unsymmetrical Anticlines in the Rocky Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1275–89.



Stages in development of structure.
(Not drawn to scale)

C.T. Jones Nov. 1938

FIG. 7

VERTICAL UPLIFT OR RAMP STRUCTURE?

All data obtained from this brief study appear to favor the more accepted theory that most of the mountain uplifts of the Rocky Mountain region, and in particular the Bridger-Owl Creek Range, were formed by vertical uplifting. Theoretically, many of the surface data in Wind River Canyon can be used as support for the ramp theory, but these same data can be more logically applied in other ways. Furthermore, the ramp theory necessitates the assumption that favorable structural features are present in the concealed subsurface.

If, as some "ramp" sponsors would explain, the several normal and reverse faults in the canyon represent slivering ahead of the steeper ramp thrust which is the secondary normal fault at Boysen Dam, then irreconcilable data become apparent. First, the slivering ahead of the main ramp should all be the reverse type of faulting; whereas, the mapping disclosed both reverse and normal faults to be present. Second, the normal fault at Boysen Dam dips 65° S. and to designate this as the ramp entails the necessity of hypothecating a change in direction and rate of dip no evidence of which was found to be present in the walls of the canyon. Third, there is such an obvious and abrupt difference in rate and direction of dip of this secondary normal fault at Boysen Dam and the other more southerly normal and reverse faults that they are difficult to correlate with the ramp theory. It would be expected that this great difference in rate and direction of dip would be distributed as a gradual change through several of these faults.

On the other hand, few data irreconcilable to the "ramp or tilted fault block" theory are present if it be assumed that the primary thrust fault is the main ramp fault. The low-angled slivering supposed to be ahead could now lie concealed by Wasatch deposition. The normal and reverse faults on the crestal area would simply represent later readjustment of a tensional condition along the ramp. In many areas of the Rocky Mountain region where thrusting is present, normal faulting is also associated with the deformation.

However, since the basement rocks of Wind River Canyon consist mainly of dioritic schists—rocks lacking the rigidity of granites—they do not qualify for the conditions demanded for proper application of the ramp theory. Some sponsors of this theory hold that basement rocks such as granite can not yield by folding, and that any differential uplifting is accomplished by ramp structure. Yet these sponsors propose the use of the structure of the Bridger-Owl Creek Range, as exposed in Wind River Canyon, as proof of their theory

even though dioritic schists predominate as the basement rock at all outcrops. The structure of Wind River Canyon can therefore hardly be a result of ramp thrusting when the required rigid granitic basement is absent.

CONCLUSION

In explaining the structure of Wind River Canyon as a result of vertical uplifting caused by subterranean horizontally applied compressive forces centered at slightly different levels, no assumed data of controversial nature are required, and all surface information is not only reconcilable but more logically applied. The low-angled primary thrust at the south portal is a result of the breaking of the strata as the anticline overturned. The secondary normal fault at Boysen Dam was formed when the crestal area became totally unsupported and broke free from the rest of the anticline. The many normal and reverse faults between the primary thrust and the secondary normal fault resulted from the uneven settling of the crestal area.

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EMBA SALT-DOME REGION, U.S.S.R., AND SOME COMPARISONS WITH OTHER SALT-DOME REGIONS[1]

C. W. SANDERS[2]
Houston, Texas

ABSTRACT

Although oil has been produced since 1908 from salt domes in the Emba area, which lies between the south end of the Ural Mountains and the north shore of the Caspian Sea, the geological situation in that region has escaped the attention of many American geologists. Salt-dome geologists of the Gulf Coast region have frequently had their attention directed to the salt structures of Germany and of Roumania, whereas greater resemblance to the Gulf Coast is to be found in the Emba district, where more than 100 salt domes are known in an area about the size of the Gulf Coast exclusive of South Texas. Future discoveries may bring the total to 300 or more salt domes, including deep ones. Only six domes are being exploited but many others have shown evidence of accumulations of oil and gas. Production has been found in "Permo-Triassic," Jurassic, and Cretaceous strata, but chiefly in Jurassic sands. The oil reserves appear to be commercially important but do not rank with those of the Gulf Coast.

The Emba mother salt series is of Permian age—probably Upper Permian. The overburden is much thinner than that of the Gulf Coast, consisting chiefly of Mesozoic strata, with local patches of Tertiary sediments, and a blanket of Quaternary (Caspian) beds in the coastal area.

Many of the shallow salt structures are larger than any Gulf Coast shallow domes. Future exploration will probably reveal an increasingly larger percentage of deep domes.

More is known about pre-salt strata in the Emba region than in the Gulf Coast because of the outcrops in the southern Urals. The Upper Carboniferous and Permian sections have been rather closely correlated by several investigators with the Pennsylvanian and Permian sections of the Mid-Continent region, largely on the basis of the ammonites contained.

Development has been slow in the Emba district due largely to the remoteness of the area, the long severe winters, and the thinness of the sands as compared with the prolific Tertiary sands of the Caucasus belt.

The tectonic setting of the Emba domes is discussed and compared with that of the salt domes of the Gulf Coast, of the North German basin, of Persia (Iran), and of the Carpathian foothills belt in Roumania.

INTRODUCTION

As regards geographic situation and size of the area, number of salt domes, their manner of growth, and their association with commercial accumulations of petroleum, the Emba area resembles the Texas-Louisiana Gulf Coast more than any other known salt-dome province in the world. The oil reserves do not appear to be of the same order of magnitude as those of the Gulf Coast, but are definitely superior to those of the German salt basin.

The known salt domes lie chiefly at shallow to intermediate depths. Future discoveries will probably include an increasingly larger percentage of deep domes, as the reflection seismograph has been in use in the Emba area only since 1935.

[1] Manuscript received, November 12, 1938.

[2] Geologist, Shell Petroleum Corporation.

It is unfortunate that so little has been published in English on such an important salt-dome region.

The writer has not visited the area but became interested in it while working in Europe in 1936, after having visited the salt-structure areas of Germany and Roumania. He had access to several pertinent translations from the Russian, and enjoyed informal discussions with geologists who had worked in Russia. Particular acknowledgment for such help is due Dr. Van der Ploeg. Thanks are due the Shell Petroleum Corporation, for permission to publish, and to B. B. Zavoico[3] for helpful discussions and for material from his files.

No claim is made for completeness or infallibility of data in this article; it is offered primarily as a general treatment of a great salt-dome area with which many American geologists are unfamiliar.

LOCATION AND AREA

The Emba salt-dome area[4] is at the southwestern edge of the Asiatic part of the Soviet Union, on the north shore of the Caspian Sea. The salt-dome area extends northeastward at least to Temir, and may include several domes in the Aktiubinsk area. Most of the domes lie between the Ural, Uil, and Emba rivers (Fig. 1 and Fig. 2).

The Emba area has been subdivided from southwest to northeast into the following districts: (1) Coastal, (2) Imankara, (3) Tersakkan, (4) Temir, and (5) Aktiubinsk.

The actual salt-dome area represented by these five districts covers more than 50,000 square miles, or about the area of the Texas-Louisiana Gulf Coast salt-dome province[5] east of Corpus Christi.

TOPOGRAPHY AND CLIMATE

Playa lakes and shallow depressions dot portions of the otherwise featureless plains of the Emba steppes which slope gently toward the Caspian Sea. (The surface of the Caspian is substantially below mean sea-level.) More topographic relief is present on the northeast, near the south plunge of the Ural Mountain folds, where the streams are intrenched in the Cretaceous plateau.[6]

The region is semi-arid, with great extremes of temperature.

[3] Geologist, department of petroleum economics, The Chase National Bank, New York.

[4] "Emba *area*" refers to the actual salt-dome area. The writer uses the term "Emba *region*" to include the whole salt-basin province.

[5] This, of course, is exclusive of the interior salt-dome province of northeast Texas and northern Louisiana.

[6] For a detailed description of topography and climate, see F. A. Holiday: "The Uralsk Province and Its Oil Fields," *Jour. Inst. Petrol. Tech.*, Vol. 2 (1915–16), pp. 87–121.

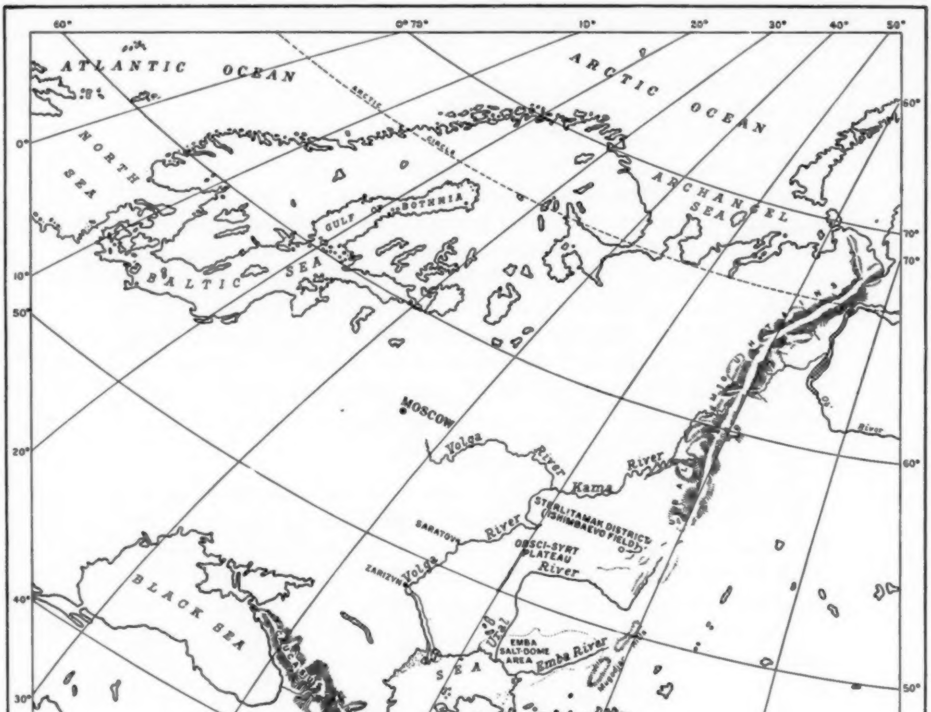
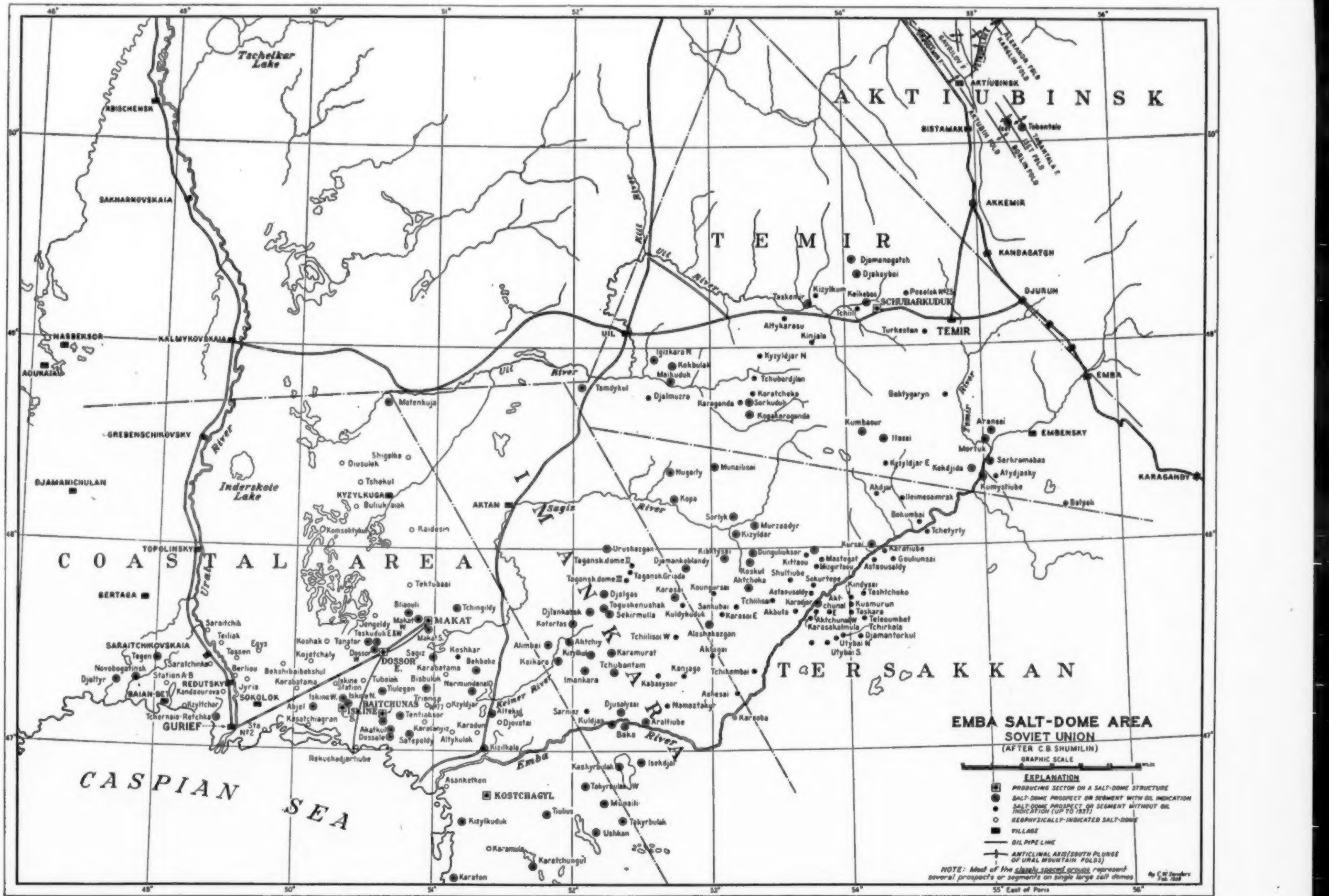


FIG. 1.—Map showing location of Emba salt-dome area.



EMBA SALT-DOME AREA
SOVIET UNION
(AFTER C.B. SHUMILIN)
GRAPHIC SCALE
EXPLANATION
PRODUCING SECTOR ON A SALT-DOME STRUCTURE
SALT-DOME PROSPECT OR SEGMENT WITH OIL INDICATION
SALT-DOME PROSPECT OR SEGMENT WITHOUT OIL INDICATION (UP TO 1937)
GEOPHYSICALLY-INDICATED SALT-DOME
VILLAGE
OIL PIPE LINE
ANTICLINAL AXIS (SOUTH PLUNGE OF URAL MOUNTAIN FOLDS)
NOTE: Most of the closely spaced groups represent several prospects or segments on single large salt domes
55° East of Paris
AKTIUBINSK
TEMIR
COASTAL AREA
TERSAKKAN
CASPIAN SEA
Tschelkar Lake
Inderskoie Lake
Ural River
Uil River
Sagiz River
Emba River
GURIEF
MAKAT
DOSSOR
BAITCHUNAS
ISKINE
KOSTCHAGYL
SOKOLOK
REDUTSKY
TOPOLINSKY
KALMYKOVSKAIA
GREBENSCHIKOVSKY
SAKHARNOVSKAIA
ABISCHENSK
HASBEKSOR
AOUKAIAD
DJAMANICHULAN
BERTAGA
KYZYLKUGA
AKTAN
UIL
TEMIR
SCHUBARKUDUK
DJURUN
KANDAGATSH
AKKEMIR
BISTAMAK
AKTIUBINSK
EMBA
EMBENSKY
KARAGANDY
SARAITCHNKOVSKAIA
BAIAN-BET

FIG. 2

HISTORY OF DEVELOPMENT

Although oil indications had been known for many years, the first flowing well was not completed until 1908, when a test at Karatchungul in the southern Coastal district flowed at the rate of 135 barrels of oil per day.[7] Serious development did not get under way until 1911, when the Dossor gusher (well No. 3) was brought in flowing at a rate of more than 100,000 barrels of oil per day from a depth of 723 feet.

The outbreak of war in 1914 checked development but the Makat area was brought into production in 1915. At that time there were 59 oil wells in the Dossor field. In 1926 an oil seep was found at Koschagyl.[8] Prospecting by the Soviets began immediately and the first test, drilled in 1931–32, found initial production of 1,700 barrels of oil per day.

Baitchunas came into production in 1931, Iskine in 1932–33, and Shubarkuduk shortly thereafter.

Wosk[9] states that oil wells are being drilled on six or eight other domes but that the production is shut in after completion.

STRATIGRAPHY

SEDIMENTS YOUNGER THAN THE SALT SERIES

Unconsolidated Caspian and fluviatile deposits cover the coastal area and extend northward along the Volga and Ural river valleys. A few patches of Tertiary are exposed in the salt-dome area, but most of the outcrops in the northeastern part of the territory are of Upper Cretaceous age. Older beds, including Comanche (Lower Cretaceous), Jurassic, and even "Permo-Triassic" are exposed as inliers over local uplifts.

The stratigraphic succession flanking the Iskine shallow salt dome (Coastal district) has been summarized[10] as shown in Table I. This, of course, represents a reduced section, due to the presence of the salt dome.

The base of the salt core at Koschagyl is estimated from gravimetric data to lie at a depth of 10,800 feet or more. The total *average* overburden above the mother salt series in the Emba area is probably between 10,000 and 15,000 feet. The minimum may be less than 10,000 feet.

[7] I. G. Permiakov, in *Petroleum Industry*, No. 4 (Moscow, 1936), pp. 26–32. (In Russian. Translated by M. Krivolai, at the present writer's request.)

[8] Anonymous, "The New Russian Oil Fields of Southern Emba," *Petroleum Times*, Vol. 30, No. 767 (London, September 23, 1933), p. 426.

[9] L. David Wosk, "How Much Crude Reserve Has U.S.S.R.?" *Oil Weekly*, Vol. 89, No. 8 (May 2, 1938), p. 32.

[10] Abstract from *Petroleum Industry*, No. 4 (Moscow, 1934).

TABLE I

Series	*Remarks*	*Approx. Thickness in Feet*
Post-Tertiary	Yellow and gray sands; sandy shale	60–90
Tertiary (Paleogene)	Green calcareous shale	590
Cretaceous (Seno-Turonian)	White chalk and marls	Up to 600
Cretaceous (Albo-Cenomanian)	Gray shale; some sand	Up to 640
Cretaceous (Aptian)	Dark gray shales	360
Comanche (Neocomian)	Present only in northern part of field. In southern part of field, Aptian rests unconformably on Jurassic	
Jurassic (Upper and Middle)	Predominantly shale; streaks of sandstone and coal	1,450
(Lower)	Sands and sandstone	
"Permo-Triassic"	Variegated clay-shale and sandstone	300?
		4,030±feet
Permian	Gypsum and salt of the salt core	

Thicknesses of 20,000–40,000 feet of overburden above the salt are postulated for the Gulf Coast, so that in the matter of overburden, the Emba area is more like the interior salt-dome province of East Texas and northern Louisiana.

AGE OF SALT

The Kungurian (Middle? Permian) of the southern Urals (Table II) contains salt and gypsum which may be the approximate correlative of the mother salt of the Emba area, but it appears more likely that the lower portion of the widespread "Permo-Triassic" red-bed series grades laterally into salt in the Emba area. That series contains salt and anhydrite in the Ishimbaevo field (Fig. 3) north of the Emba area, and comprises red beds over much of the eastern Russian plains. The series is predominantly of Upper Permian age but may include some Triassic beds at the top. The salt of the Emba salt domes intrudes the upper portion of the "Permo-Triassic" red beds but has not been found to intrude any older strata, hence the salt is believed to be of Upper Permian age. The Zechstein salt of the North German basin is also Upper Permian.

PRE-SALT SEDIMENTS IN SOUTHERN URALS

Elias[11] has reviewed some work by Ružencez and others on the Carboniferous and Permian of the southern Urals, northeast of the main salt-dome area. Correlations have been based largely on deter-

[11] M. K. Elias, "Carboniferous and Permian of the Southern Urals," *Amer. Jour. Sci.*, 5th Ser., Vol. 33, No. 196 (April, 1937), pp. 279–95.

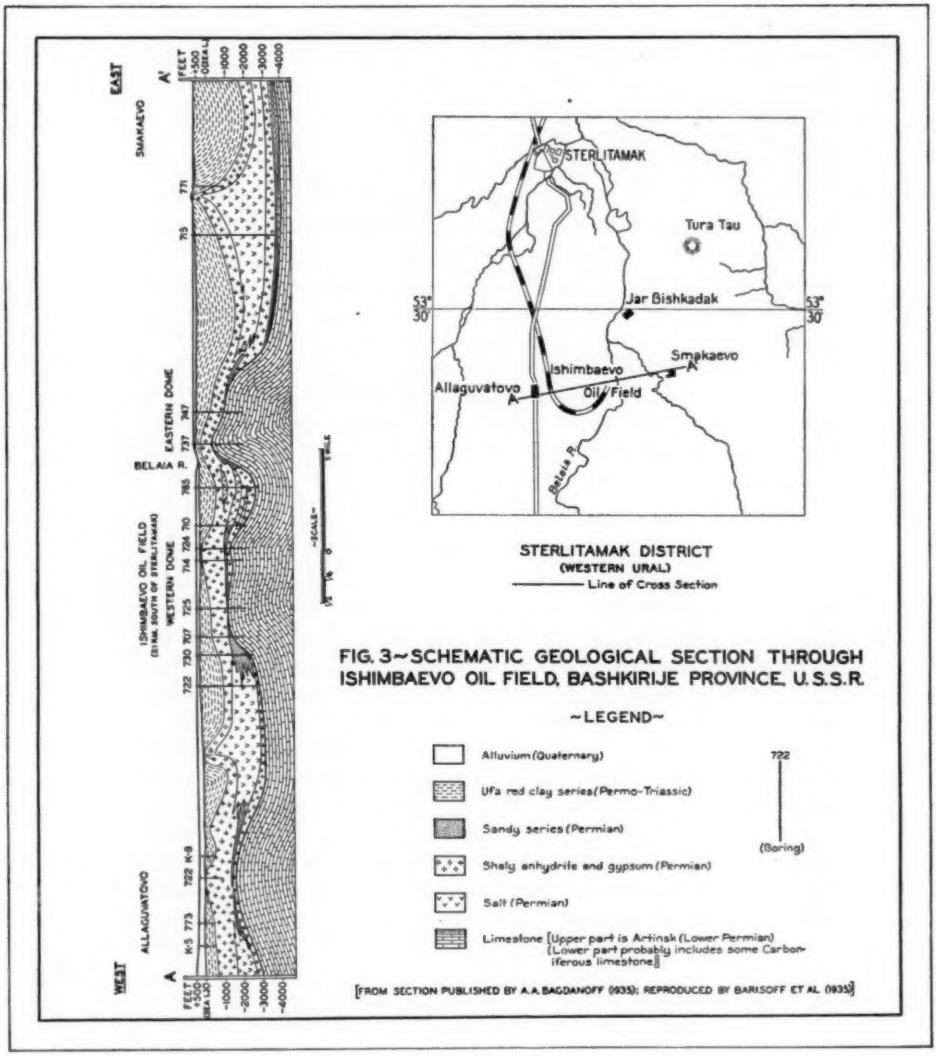

STERLITAMAK
Tura Tau
Jar Bishkadak
53° 30'
Smakaevo
Ishimbaevo Oil Field
Allaguvatovo
A
A'
Belaia R.
STERLITAMAK DISTRICT
(WESTERN URAL)
Line of Cross Section
WEST
EAST
ALLAGUVATOVO
ISHIMBAEVO OIL FIELD
WESTERN DOME
EASTERN DOME
BELAIA R.
SMAKAEVO
FEET
-1000
-2000
-3000
-4000
~SCALE~
FIG. 3~SCHEMATIC GEOLOGICAL SECTION THROUGH ISHIMBAEVO OIL FIELD, BASHKIRIJE PROVINCE, U.S.S.R.
~LEGEND~
Alluvium (Quaternary)
Ufa red clay series (Permo-Triassic)
Sandy series (Permian)
Shaly anhydrite and gypsum (Permian)
Salt (Permian)
Limestone [Upper part is Artinsk (Lower Permian) (Lower part probably includes some Carboniferous limestone)]
722
(Boring)
[FROM SECTION PUBLISHED BY A.A. BAGDANOFF (1935); REPRODUCED BY BARISOFF ET AL. (1935)]

FIG. 3

minations of the ammonite zones. Plummer,[12] Dunbar,[13] and Miller[14] have reviewed and discussed the correlations. The present writer has summarized the main features of these correlations and reviews in Table II.

REGIONAL STRUCTURE

The geographic relation of the Emba area to the Caspian Sea and to the Ural Mountains is not unlike that of the Gulf Coast salt-dome area to the Gulf of Mexico and to the Appalachian Mountains, except that the Appalachians plunge southwestward toward the salt-dome area, whereas the Urals plunge southward. The southern extension of the Uralian folding lies immediately east of the Ust-Urt block (Fig. 1) and thence probably swings eastward. Both mountain systems represent late Paleozoic orogenies of early Paleozoic geosynclines.

The Emba area is in the northeastern part of the Caspian basin. A simplified picture of the Caspian basin may be gained by thinking first of the great region to the north, where the eastern Russian plains stretch westward away from the Ural Mountains. This table-land comprises nearly flat Paleozoic strata, with Permian Red-beds cropping out in a large part. It dips gently westward and, in the southern part, southward. The gentle south dip gradually assumes the form of a broad southward-plunging trough, the south end of which is occupied by the Caspian Sea. The Permian Red-beds which crop out in the plateau area probably change laterally to an evaporite series in the Emba area where the mother salt is believed to occur at depths of 10,000 to 15,000 feet. The actual extent of the salt basin within the present Caspian basin is not known but gravity anomalies suggest that the salt-dome area may extend westward to Volga River.[15]

The Caspian basin may be considered to be bounded roughly as follows: on the north by the eastern Russian plateau or table-land, on the northeast and east by the Ural Mountains and their southern extensions such as the Mugodjar Hills; on the southeast by the rigid, stable Ust-Urt block. On the south and southwest it is either bounded or interrupted by the strong Tertiary folds of the Caucasus system, and on the west by a probable normal fault zone along the Volga River valley between Stalingrad (Zarizyn) and Saratov. The Volga

[12] F. B. Plummer, "Notes on the Correlation of Russian and Mid-Continent Carboniferous and Permian Ammonite Zones," *Amer. Jour. Sci.*, 5th Ser., Vol. 33, No. 198 (June, 1937), pp. 462–69.

[13] Carl O. Dunbar, "On the Carboniferous and Permian of the Southern Urals," *ibid.*, pp. 470–71.

[14] A. K. Miller, *ibid.*, pp. 471–72.

[15] V. Selsky, in *Petroleum Times*, Vol. 30 (1933), p. 252.

TABLE II
Carboniferous and Permian of Southern Urals

Name	*Age*	*Lithology*	*Approx. Thickness in Feet*	*Remarks*
Kungurian	Middle (?) Permian	Upper group: clay, sandstone, marl Lower group: gypsum; salt locally	500– 830 250– 500	Grades laterally into thick bituminous limestone (1,650–2,310 feet)
Artinskian	Lower Permian	Predominantly clay; some coarse conglomerate, dolomitic limestone, sandstone, and marl	2,100–4,000	Approx. equivalent of Leonard of Texas (Dunbar)
Sakmarian	Basal Permian (?)	Clay, sandstone, conglomerate, limestone (part bituminous)	4,000	Upper part corresponds with basal Wolfcamp of Texas and lower Big Blue of Kansas (Plummer)
Uralian	Upper Carboniferous	Characterized by disappearance of coarser clastics and predominance of clays *Aktiubinsk area:* Upper series: thick sandy shale and marl Lower series: predominant limestone with glacial breccias (*Disconformity*)	2,000	Probably Canyon and basal Cisco equivalents (Plummer)
Moscovian	Middle Carboniferous	Sandy clays and sandstones, with local, gigantic breccias interpreted as submarine landslides	3,300–5,000	Basal part equivalent to upper Bendian and Pottsville (Plummer)
Namurian-Viséan	Lower Carboniferous	Dark siliceous shales; limestone	5,100	Mississippian and possible Lower Pennsylvanian.

at Stalingrad (Zarizyn) turns abruptly away from the probable fault zone and flows southeastward to the Caspian Sea (Fig. 1).

The abrupt right-angle turn in Ural River (Fig. 1) is also noteworthy. It flows westward from the Ural Mountains and thence southward to the Caspian Sea. As no lithologic or structural barrier is evident in geologic maps of the area, the southward turn suggests the presence of a topographic reflection of the broad southward-plunging synclinal zone of the upper Caspian basin, down or near which the river flows into the Caspian Sea. The lower Ural River is near the west edge of the known salt-dome area. The regional dip in the salt-dome area is southwestward.

The Apsheron Peninsula with its prolific oil fields is on the west shore of the Caspian Sea, several hundred miles southwest of the Emba area, in the belt of the strong Tertiary folds of the Caucasus system.

The strata of the Emba area to known depths have not been strongly folded. Weak north-south folds were induced by the final movements of the Ural Mountain folding at the close of the Paleozoic and persisting into Mesozoic time. According to Von Bubnoff,[16] the later Mesozoic and early Tertiary folding did not simply accentuate the old north-south grain but, rather, tended to form generally northwest-southeast folds. This direction anticipated the trend of the strong late Tertiary (Ammodez-Mangyschlak) trend across the Caspian Sea. The gradual change from north-south to northwest-southeast trends resulted in a torsional influence which is believed to have induced some of the faulting in the Emba area. The faults, in turn, may have localized and initiated growth of some of the salt domes.

Further weak disturbances affected the salt-dome area in Pliocene time. This folding is stronger toward the southwest, near the delta of Ural River. The northwest-southeast to north-northwest south-southeast trend is evident in the elongations of some of the shallow domes.

The latest known disturbances in the southern Urals are post-Pliocene.[17]

In the Obsci-Syrt plateau, north of the Emba basin, the weak Uralian north-south folds are crossed by nearly east-west post-Cretaceous folds.[18]

[16] A. von Bubnoff, *Geologie von Europa*, Band I (Berlin, 1926), p. 126.

[17] Anatole Safonov, "Orogeny in the Urals," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 11 (November, 1937), p. 1456.

[18] A. H. Redfield, "The Petroleum Resources of Russia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 5 (May, 1927), p. 509.

The lack of strong folds in post-Paleozoic strata in the southern Ural Mountains (northeast of the salt-dome area) was noted by Elias,[19] among others. He remarked that "the plunging late Paleozoic folds are overlapped by horizontal Mesozoic (mostly Jurassic) and Tertiary rocks."

With further reference to the actual salt-dome area, Von Bubnoff[20] followed Tikhonovitch in postulating a series comprising five broad north-south anticlinal zones supposedly formed by the growth of generally north-south trending rows of salt domes. With the subsequent finding of so many more shallow domes, however, many of which lie in the intervening belts, it becomes more difficult, if not impossible, to adhere to that early conception. The areal distribution of deep and shallow domes would probably be more significant,[21] but such a map for the Emba area is not available.

Von Bubnoff also postulated (after Tikhonovitch) a transverse synclinal axis along the south edge of the present salt-dome area. The older strata probably rise from near that line to the Ust-Urt rigid block. It appears to the present writer that salt domes (perhaps only deep ones) should be found in the intervening territory between the known salt domes and the Ust-Urt block unless the axis drawn by Tikhonovitch really represents the northwest edge of a high fault block which formed the southeastern limit of salt deposition.

SALT DOMES

GENERAL STATEMENT

Although the map (Fig. 2) shows a total of 288 prospects and fields, it must be emphasized that these are not all separate salt domes. In many places two or three prospects or producing sectors are shown where a single large salt structure is known to be present. An example is Iskine, N. Iskine, and W. Iskine, which are simply different producing sectors on the same salt dome. The writer has been unable to find a map showing the outlines and number of *separate* salt structures. Zavoico stated[22] that approximately 250 salt domes had been found through 1937, but he now admits that this figure is probably too high due to the aforementioned Soviet custom of por-

[19] M. K. Elias, *op. cit.*, p. 281.

[20] *Op. cit.*, p. 127.

[21] See Donald Barton's article on "Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Salt Domes of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), pp. 1025–83, particularly Figure 5.

[22] B. B. Zavoico, "Russian Oil Fields in 1937," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 6 (June, 1938), p. 759.

traying mere salients or sectors as separate domes. If all closely spaced designations on the map (Fig. 2) are grouped, a total of perhaps 100–110 separate salt structures is suggested.

CLASSIFICATION

A depth classification seems to this writer greatly preferable to the ambiguous terms "piercement" and "non-piercement." A dome which is "non-piercement" insofar as certain objective Miocene sands are concerned, may be found to be a "piercement" dome in relation to Oligocene objectives. Hanna[23] uses the terms "piercement" and "non-piercement" in the sense of intrusive (or diapiric) and non-intrusive, which usage is sound in itself but is likely to be confused with the non-technical oil operator's common usage to connote the relation of the salt mass to the objective oil horizons.

The Emba domes may be classified primarily in accordance with the following depth classification which the writer has been using for the Gulf Coast.

1. *Deep domes:* those in which salt-dome material occurs at a depth of 5,000 feet (±1,525 meters) or more. Example: Karaton (?), southern Coastal district
2. *Intermediate-depth domes:* those whose tops (salt-dome material) occur at depths between 3,500 and 5,000 feet. (Karaton may be found to belong to this group.)
3. *Shallow domes:* those whose tops (salt-dome material) occur at depths of less than 3,500 feet (±1,067 meters). Examples: Iskine (Fig. 4), Dossor (Fig. 5), Koschagyl (Fig. 6).

The deep domes in general represent a "primary stage of development," as noted by Permiakov,[24] but it must be kept in mind that deep domes are not necessarily young domes, in *actual* age. Many deep domes are old, even though in a "primary stage of development." Some of them have probably exhausted or nearly exhausted the salt supply within their individual peripheral synclines.[25] Active deep domes are known, however.

Salt domes may be further classified according to their shape in vertical cross section. The downwardly enlarging or stock type of dome probably represents a less mature stage of development than the plug or spine type. The latter is characterized by a flat top, steep flanks, and, commonly, well developed cap rock. This is Permiakov's "fully developed stage," and it seems probable that most of the plug-type domes, such as Jennings, Spindletop, Fannett, and Barbers Hill,

[23] Marcus A. Hanna, "Geology of the Gulf Coast Salt Domes," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 644–46.

[24] I. G. Permiakov, *op. cit.*

[25] See experiments by L. L. Nettleton, "Fluid Mechanics of Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 9 (September, 1934), pp. 1175–1204.

ISKINE

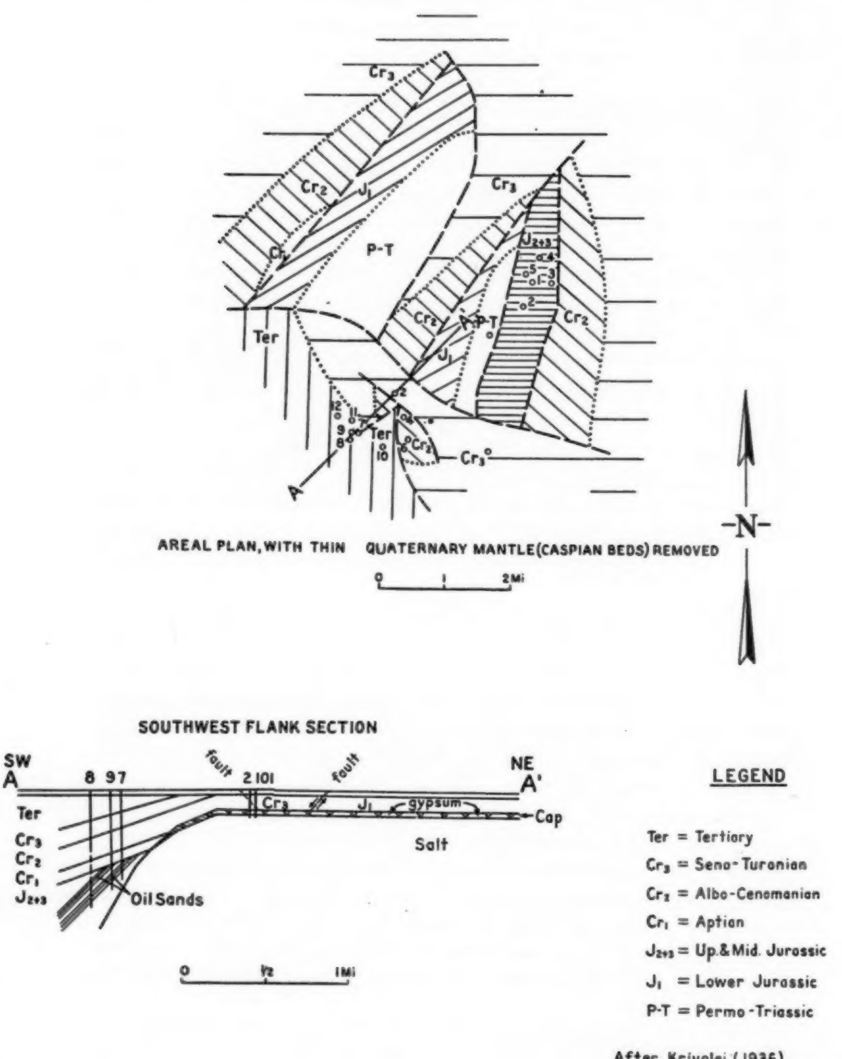

Cr3
Cr2
J1
Cr1
P-T
Cr3
J2+3
Cr2
Cr2
A'
P-T
J1
Ter
Ter
Cr2
Cr3
A
AREAL PLAN, WITH THIN QUATERNARY MANTLE (CASPIAN BEDS) REMOVED
0 1 2Mi
-N-
SOUTHWEST FLANK SECTION
SW
A
8 9 7
fault
2 101
fault
NE
A'
Cr3
J1
gypsum
Cap
Ter
Cr3
Cr2
Cr1
J2+3
Salt
Oil Sands
0 1/2 1Mi
LEGEND
Ter = Tertiary
Cr3 = Seno-Turonian
Cr2 = Albo-Cenomanian
Cr1 = Aptian
J2+3 = Up. & Mid. Jurassic
J1 = Lower Jurassic
P-T = Permo-Triassic
After Krivolai (1936)
from drawings in Petrol. Industry
(Moscow).

FIG. 4

on the Texas Gulf Coast, do represent a stage approaching full development, with more complete upward redistribution of salt and consequent narrowing of the salt spine at depth. Cap-rock overhang, chiefly due to solution of salt beneath the cap rock, is a common feature of such domes on the Gulf Coast, but the writer has found no mention of overhang in the Emba area.

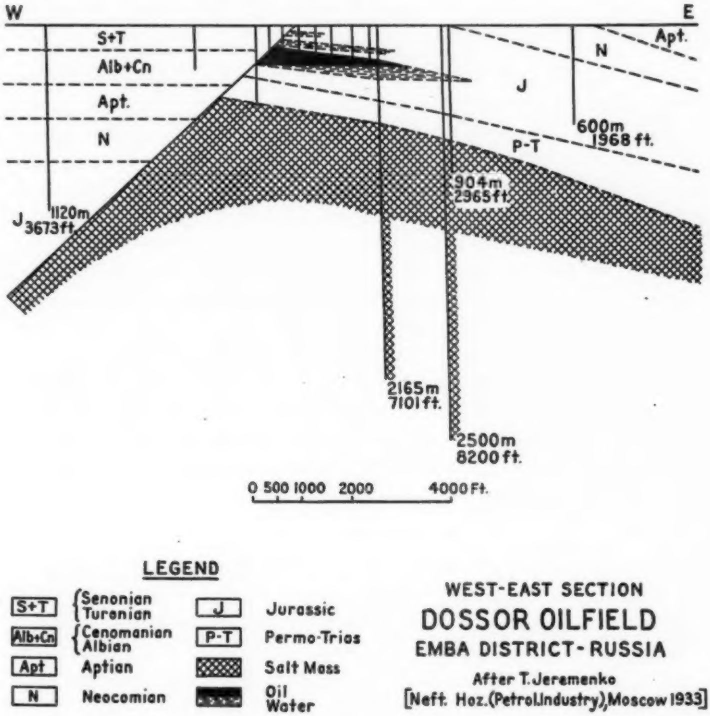


FIG. 5

Emba salt domes are further classified by Soviet geologists according to the shape, in plan, of the shallow overlying structures: star-shaped, like Dossor; triangular, like Iskine; long-oval type, like Asanketken; and compound types resulting from coalescence of two or more salt intrusions, as at Baitchunas.

The central Emba salt masses, according to Permiakov, attain diameters of 5–12 kilometers (3.1–7.5 miles), whereas those at the

south are of smaller average diameter. The largest shallow Emba domes are therefore larger than any Gulf Coast shallow salt masses but not much longer than the Boggy Creek salt mass (Anderson and Cherokee counties, eastern Texas), which is nearly 6 miles in length. The largest known shallow salt dome on the Gulf Coast is Boling (Fort Bend and Wharton counties, Texas) which is approximately 5 miles in greatest diameter at a depth of 4,000 feet.

CAP ROCK

The writer believes that there can be little doubt that cap rock is formed by concentration of disseminated primary anhydrite grains and beds through solution of salt near the surface in the rising plugs. Cap rock is rarely found on deep domes. Anhydrite cap on the shallow domes alters locally to gypsum and impure limestone. Cap rock is mentioned in connection with several Emba shallow salt domes and is probably as common as that of the American salt domes. Koschagyl, for example, has a gypsum cap up to 125 feet thick, forming a thimble sheath similar to the cap of the Gulf Coast domes. A similar cap is present on the Iskine dome (Fig. 4).

Thickness of cap rock, of course, can not be used empirically as a criterion for "fully developed" domes. Some definitely old shallow salt masses, such as West Columbia, Brazoria County, Texas, have relatively thin cap rock, probably due to partial solution of several generations of cap rock in slightly acidic ground water, or to relative initial purity of the salt.

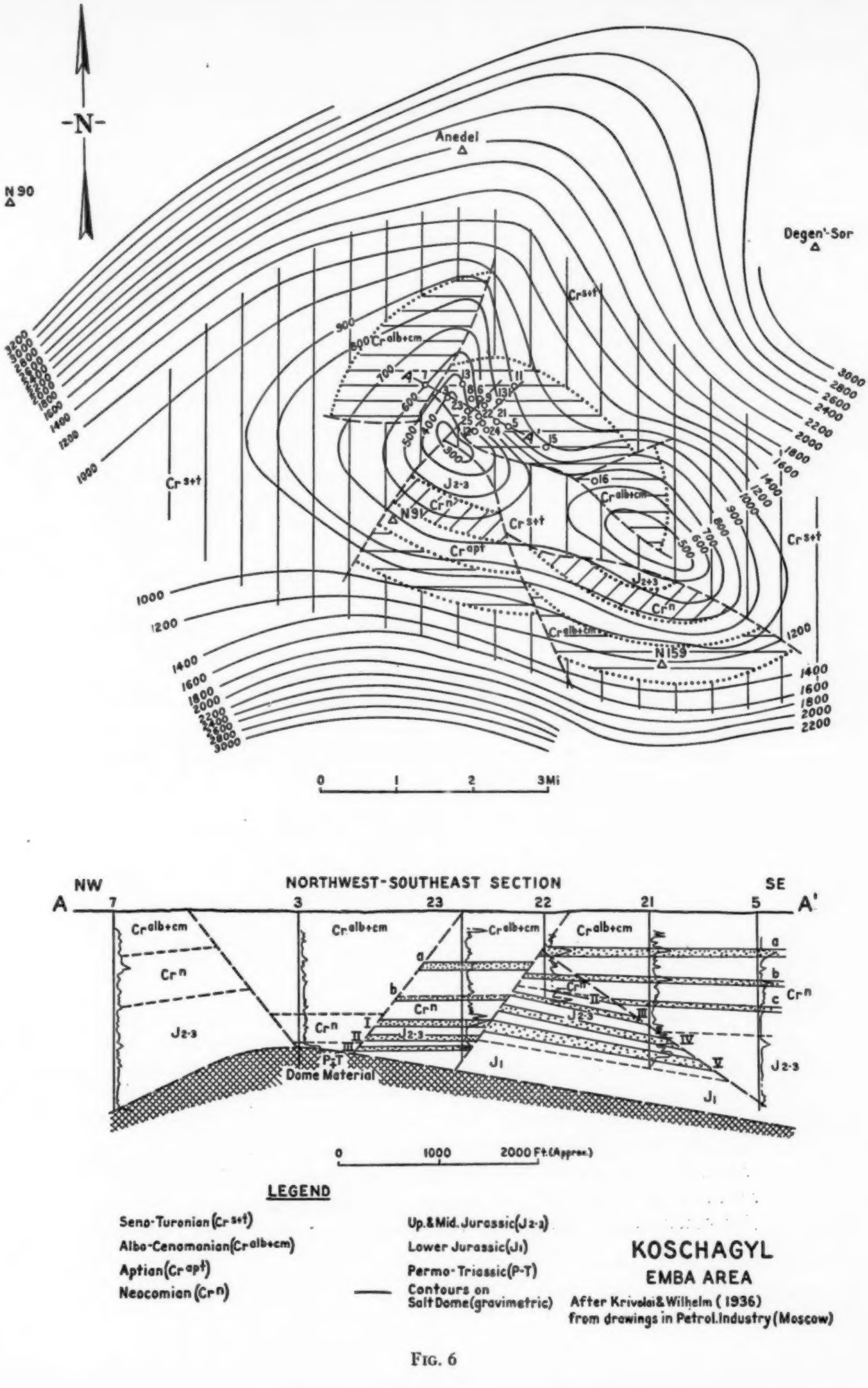
ACCUMULATION OF OIL

Although the first flowing well in the Emba area was obtained in 1908 from the gypsum cap of Karachungul[26] at a depth of only 138 feet, accumulations of oil in cap rock have to date proved to be of non-commercial magnitude.

Shallow super-cap accumulations associated with faulting have been found in the Jurassic at Dossor (Fig. 5), and in Jurassic, Comanche, and Cretaceous beds at Koschagyl (Fig. 6) at depths of 400–2,100 feet or more. Both of these are shallow salt domes in the Coastal district.

Steep flanking sands have contributed most of the oil in the Emba area. The best developed field of this type is Iskine, Coastal district, where steep flanking Jurassic sands are found productive beneath overlapping Neocomian beds (Fig. 4). At Makat, another shallow dome in the Coastal district, oil has accumulated in the secondary

[26] Coastal district, south of Koschagyl.



-N-
Anedel
N 90
Degen'-Sor
N91
N159
0 1 2 3Mi
NORTHWEST-SOUTHEAST SECTION
NW
SE
A
A'
Dome Material
0 1000 2000 Ft.(Approx.)
LEGEND
Seno-Turonian(Cr s+t)
Albo-Cenomanian(Cr alb+cm)
Aptian(Cr apt)
Neocomian(Cr n)
Up.&Mid. Jurassic(J 2-3)
Lower Jurassic(J1)
Permo-Triassic(P-T)
Contours on Salt Dome(gravimetric)
KOSCHAGYL
EMBA AREA
After Krivolai & Wilhelm (1936)
from drawings in Petrol. Industry (Moscow)

FIG. 6

folds near the steep flank zones. Oil has been found on some domes in flanking "Permo-Triassic" sands.

Deeper over-arching sands have been prospected on only a few domes, such as Karaton, southern Coastal area, where a gently dipping structure in Mesozoic strata covers some 4,000 acres. The central and southern parts produce oil from the Aptian (Cretaceous), and the Neocomian is saturated with oil near a fault. Test No. 7 crossed this fault at 3,940 feet, and, according to Permiakov, found saturated sands in the Jurassic. This test was abandoned after a blow-out, and the results of later testing, if any has been done, are not known to the present writer.

It is reported that the seismograph has revealed a variety of deep structures between shallow salt domes, some of which will probably be found productive. Some of these may be residual salt structures.

Structures really "deep" in the Gulf Coast sense have not yet been prospected in the Emba area.

FAULTS AND LOCAL OVERLAPS

Illustrations of Emba domes, such as are here reproduced in Figures 4, 5, and 6, show tensional fault systems strikingly similar to those of the Gulf Coast domes. The central graben and subsidiary faults at Koschagyl (Fig. 6) are typical. The main fault as shown in Figure 5, Dossor field, however, appears to be a continuation of the steeper flank of the salt mass, thereby resembling some European salt domes more than those of the Gulf Coast. The termination or bounding of the west side of the Dossor salt mass by such a fault may, on the other hand, be largely hypothetical. Control is lacking on the particular line of the cross section shown, but the fault is known to constitute a trap for oil on its upthrown side.

A large salt structure with a longitudinal central graben is known at Munaili (or Manouli) at the southeast edge of the Coastal district. A small amount of heavy oil has been found in Cretaceous chalk at shallow depths on that prospect.

Local overlaps on salt structures are exemplified by the situation at Iskine (Fig. 4), where dips of 10–15° in Upper Neocomian beds directly overlie dips of 20–35° in overlapped beds of Lower Neocomian and Jurassic age, pointing to important movements during or at the close of Lower Neocomian. Iskine also shows evidence of pre-Aptian (Cretaceous) uplift and of pre-Albo-Cenomanian uplift and erosion, the Albo-Cenomanian being in local contact with Jurassic beds. Approximately 1,200 feet of section comprising uppermost Jurassic, Neocomian, and Aptian is locally missing.

PRODUCTION

Although more than 20 domes have shown oil in varying quantities, only six fields are being exploited: Makat, Dossor, Iskine, Baitchunas, Koschagyl, and Shubarkuduk. Permiakov states that 20 per cent of the wells tapping shallow oil accumulations produce, during the first year, about 300–600 barrels of oil per day and that 80 per cent yield 30–60 barrels of oil per day. The oil varies from 16° to 43° A.P.I. at Dossor, the gravity decreasing with depth at both Dossor and Makat,[27] which are the two most important fields to date. The average gravity at Dossor, according to Redfield,[28] is 32.8° A.P.I., yielding 20 per cent of kerosene, and 38 per cent of fuel oil. Makat produces from Neocomian, from three sands in the Upper and Middle Jurassic, and from the "Permo-Triassic."

The following zones have been found productive at Koschagyl (Fig. 6).

1. Albian
2. Upper Neocomian
3. Lower Neocomian
4. Jurassic (a)
5. Jurassic (b) Cut out locally by Upper Neocomian overlap
6. Jurassic (c)
7. Jurassic (d)
8. Jurassic (e)
9. Jurassic (f) Opened in 1935 with well producing 300+ barrels of oil per day

It is believed that the Lower Jurassic may be found productive on the deeper flanks. The "Permo-Triassic" is productive at Makat and may also produce at Koschagyl, where it should be found on the flanks at depths of 7,000 feet or more.

The annual production figures (page 510) for the Emba area, taken from an article by Zavoico,[29] reflect the beginning of Civil War in 1918, and, in their general uniformity from 1914 to date, the lack of intensive and extensive development.

The daily average production during 1937 is reported as 7,900 barrels of oil, and that for the early part of 1938 is estimated at 8,200 barrels of oil.

SOURCE OF OIL

As most of the oil to date has been found in Jurassic sands, the associated marine Jurassic shales seem to be the most logical source of the Emba oil. The presence of oil in "Permo-Triassic" beds, how-

[27] Tchepinsky, *Les Régions Petrolifères Russes* (Paris, 1927).

[28] A. H. Redfield, *op. cit.*, p. 509.

[29] B. B. Zavoico, "Russian Oil Industry in 1937," *Trans. Amer. Inst. Min. Eng.*, Vol. 127, Petroleum Division, Ann. Report, p. 690.

Year	Approximate Production in Barrels
1911	125,500
1912	116,400
1913	819,700
1914	1,901,400
1915	1;899,300
1916	1,774,600
1917	1,783,600
1918	1,016,200
1919	185,400
1920	211,200
1920–21	400,100
1921–22	933,300
1922–23	927,700
1923–24	874,700
1924–25	1,358,500
1925–26	1,520,200
1926–27	1,766,900
1927–28	1,741,100
1928–29	1,875,600
1929–30	2,381,600
1930 (Sp. Quarter)	584,100
1931	2,270,100
1932	1,721,600
1933	1,368,900
1934	1,684,000
1935	1,912,600
1936	2,100,000
1937	2,900,000
Total	38,154,300

ever, suggests that Permian strata may constitute an additional and deeper source. Some Soviet writers believe that Permian limestone beds older than the salt have contributed most of the oil. Proponents of such a source point to the presence of petroliferous strata below the salt in the Ural Mountain area northeast of the Emba area. Whatever the source beds may be in the Emba area, they appear to be rather lean as compared with the prolific Tertiary source beds of the Gulf Coast.

Oil in the Ishimbaevo area (Fig. 3) north of the Emba district must have originated either in the Lower Permian limestone in which it is found, or in the underlying Carboniferous and Devonian. The Carboniferous and Devonian shales are bituminous at the north, containing tar shales which have yielded 5–17 per cent of tar.[30]

EXPLORATION

Methods of exploration in the Emba region have followed in general chronological order those of the Gulf Coast with the exception that the refraction seismograph seems not to have been much utilized.

[30] T. G. Madgwick, "Some Aspects of the Occurrence of Oil in Russia," *Jour. Inst. Petrol. Tech.*, Vol. 9 (1923), pp. 2–32.

Electrical surveys and soil-gas analyses seem to have been employed earlier than on the Gulf Coast, but the Soviets have been more concerned in the latter method with free gas than with adsorbed gas.

Exploratory drilling to 1932 was based only on geological mapping, although some gravimetric and electrical data were used in compiling geological maps. From 1932 to 1935, gravimetric and electrical methods were applied to the search for salt domes and the delineation of their flank structures. Reflection seismograph surveys were begun in 1935. Good reflections have been obtained down to depths of 12,000 feet, and in some places to 18,000 feet.

Soil-gas surveys have been conducted over a large part of the salt-dome area. Deep exploratory drilling since 1935 has been generally preceded by: (1) detailed gravimetrical survey, (2) soil-gas survey, (3) seismograph survey, and (4) core drilling.

Little progress has been made toward opening new reserves during the past 2 years.

The following reasons for the slow development to date are cited by Krivolai:[31] (1) complexity of the structures; (2) thinness of the oil sands as compared with the Tertiary sands on the Apsheron Peninsula; (3) lack of transportation facilities, water, electrical power, and workshops for mechanical repairs; and (4) great extremes of temperature.

Material for Emba is commonly shipped to Astrakhan and thence via the Caspian Sea to Guriev, but navigation is closed on the north Caspian during 5 winter months.

COMPARISONS WITH OTHER SALT-DOME AREAS

Although the question of *inception* of salt-dome growth has not been satisfactorily solved, the manner of *continued growth* is better understood, and may be divided into two classes: (1) isostatic growth in regions of tension, where a thick overburden[32] is required to render the salt plastic and to set up a sufficient density differential between the salt and associated deep sediments, and (2) growth in regions of strong compression, where the amount of overburden is of secondary importance. These two classifications, of course, comprise many gradations. Moreover, actual conditions may change markedly within a single region during the period of growth of a group of salt domes.

The Gulf Coast province constitutes the best known example of the first classification. From such a salt-dome region of predominant tension, to the salt-anticline areas of extreme compression, the follow-

[31] Personal communication.

[32] Probably a minimum thickness of 10,000 feet.

ing roughly gradational series may be listed: (1) the Gulf Coast, United States of America, (2) the Emba area and the German salt-dome area north of Aller River, (3) the German salt-anticline area south of Aller River, and (4) the Roumanian diapiric structures of the Carpathian thrust-front.

The Emba area resembles the Gulf Coast province in many respects but has experienced several definite periods of compressive folding. Although this folding is classified by Von Bubnoff as relatively weak, yet its effect on the salt would naturally have been more pronounced than on most of the other sediments. Some individual domes show evidence of salt movement as early as mid-Mesozoic time, when the overburden was probably much too thin to induce purely isostatic salt flowage. The Gulf Coast may have experienced similar relatively weak folding in Mesozoic time, the effects of which have been obscured by the thick Tertiary section.

The main salt of the North German basin is of Zechstein (Upper Permian) age,—probably nearly the same age as the mother salt of the Emba area.

The Emba salt domes and those of the North German basin have apparently grown under similar structural conditions, but the analogy is probably closer between the Emba domes and the German domes north of Aller River than with the German salt structures south of Aller River. The map (Fig. 7) shows the transitional character within the North German basin. Stille[33] stated:

> Certain zones of uplift can be traced from the peripheral areas far into the North German basin, and with the advance into the latter along one and the same line of uplift, the form of the salt anticline goes over more and more into the form of the salt stock.

Salt flowage was obviously initiated along two main tectonic trends,—the Saxonian and the Rhenish. A study of detailed cross sections through the German structures shows that the intermittent relative upward movements of salt have occurred largely between late Comanche and Middle Tertiary time. A few commenced growing in early Comanche time and ceased relative upward movement after a short period of growth.

The salt structures shown on the map (Fig. 7) are all shallow, but deep ones are known, particularly on the northwest.

The sedimentary overburden above the mother salt series in the main salt-dome area ranges from about 10,000 to 16,000 feet, or more, and is thus of the same order of magnitude as that postulated

[33] Hans Stille, "The Upthrust of the Salt Masses of Germany," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), p. 431.

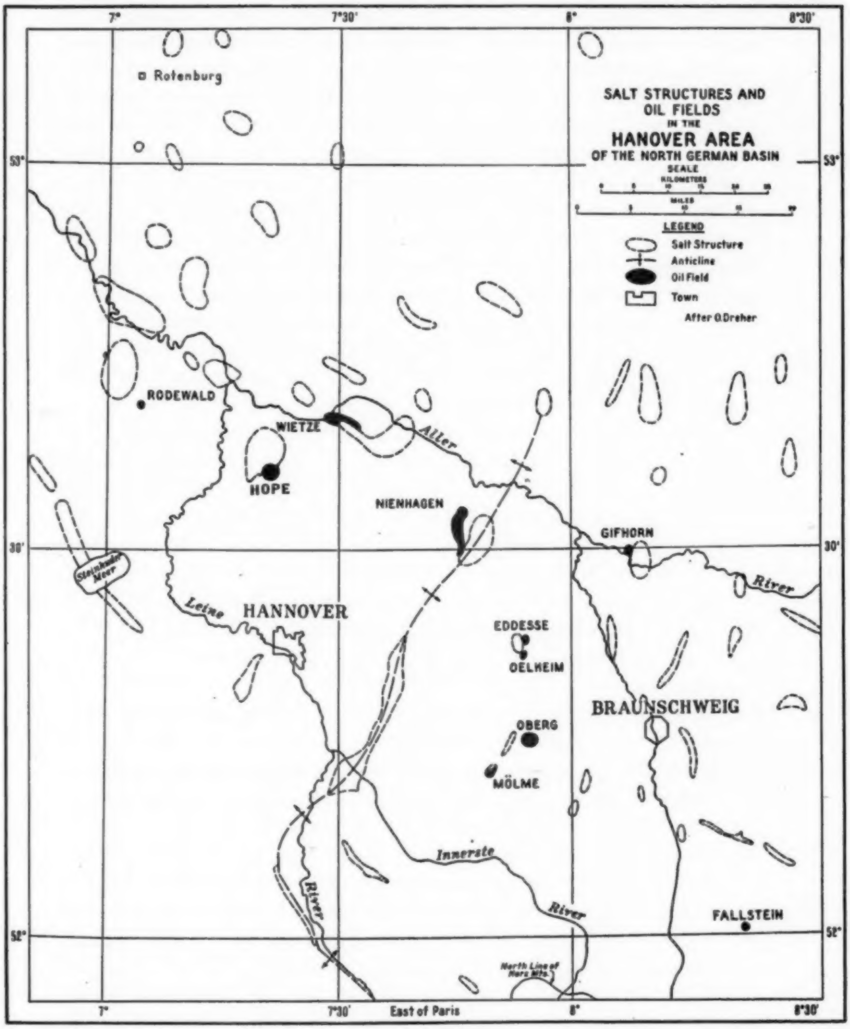

SALT STRUCTURES AND OIL FIELDS IN THE HANOVER AREA OF THE NORTH GERMAN BASIN
SCALE
KILOMETERS
MILES
LEGEND
Salt Structure
Anticline
Oil Field
Town
After O. Dreher
Rotenburg
RODEWALD
WIETZE
HOPE
NIENHAGEN
GIFHORN
HANNOVER
EDDESSE
OELHEIM
OBERG
MÖLME
BRAUNSCHWEIG
FALLSTEIN
Aller
Leine
Innerste
River
Steinhuder Meer
North Line of Harz Mts.
East of Paris
7°
7°30'
8°
8°30'
53°
30'
52°

FIG. 7

for the Emba area. It is not unlikely that local areas in the Emba district may have overburdens of less than 10,000 feet thickness, corresponding with the area in Germany between the Harz Mountains and the Flechting Ridge, where the overburden between structures is generally less than 6,000 feet. That area contains some incipient salt structures. Growth in the early stages was probably due more to tectonic than to isostatic forces, and the lack of continued growth is attributable to the relative thinness of the overburden. (This is probably also true of the two incipient salt structures shown in Figure 3, Ishimbaevo district north of the Emba area.) South of the Harz Mountains, where the overburden is still thinner (generally 1,000–3,500 feet), no *intrusive* salt structures are known. Potash is mined in that area in the flat to regionally dipping Zechstein series. The salt series is locally thickened on anticlinal noses but without penetration of the overlying, practically horizontal Buntsandstein (Lower Triassic).

The Iranian (Persian) salt-dome area also falls into a tectonic class intermediate between that of the Gulf Coast and that of the Hanover area, Germany. The northeastern border of the Persian Gulf is characterized by great elongate simple folds, with amplitudes reaching 15,000 feet.[34] The faulting is chiefly thrusting, with displacements to as much as 20,000 feet.

Lees[35] states that the domes "are mostly associated with anticlines, but in many cases they are not located on the highest parts of the structure but rather on the pitching ends or flanks," and that "some are situated in synclines." The local association with synclines and the fact that they are chiefly of round or oval form distinguishes them from the Roumanian type. The Iranian mother salt is believed to be of Cambrian age, whereas the main folding and thrusting took place in Piocene time. Lees suggested that the lack of demonstrable connection between some of the salt domes and the regional folds may indicate that the uprise of salt had begun prior to the principal folding. In fact, there is strong evidence that at least one dome was exposed to erosion in late Cretaceous time.[36] Others seem to have been well formed in early Tertiary time.

The Iranian domes probably began their growth under regional tensional conditions, but experienced a strong late Tertiary compres-

[34] J. V. Harrison, "Salt Domes in Persia," *Jour. Inst. Petrol. Tech.*, Vol. 17, No. 91 (May, 1931), p. 311.

[35] G. M. Lees, "Salt—Some Depositional and Deformational Problems," *op. cit.*, p. 275.

[36] J. V. Harrison, *op. cit.*, p. 314.

sive stage which was lacking on the Gulf Coast and weak in the Ural-Emba region. Many of the domes have probably continued their relative upward growth since the strong folding subsided.

In the Carpathian thrust belt of Roumania, diapiric structures are associated with strong folding and thrust-faulting. In that belt, the writer was surprised to see that many of the "salt anticlines" have diapiric clay cores, with little or no shallow rock salt in evidence. The intrusive gray clay is termed "salt formation" because in many diapiric cores it is associated with rock salt. It resembles the Vicksburg "heaving shale" of the Gulf Coast. The point the writer wishes to bring out in this connection is that the presence of the rock salt in many of the Roumanian diapiric folds appears to be largely fortuitous; the salt is *not a requisite of the diapirism* in those strongly squeezed and broken folds.[37] The plastic clay would have been present alone in such diapiric cores had there been no salt involved in the section, as may be inferred from the fact that similar diapiric folds such as those of the Caucasus have intrusive cores of marl and clay, with no salt. It is noteworthy that the main intrusive clay is probably of Helvetian (Miocene) age in Roumania and of Maikop (Miocene) age in the Caucasus foothills. *These beds are approximately correlative.* Most Roumanian geologists believe that the intrusive salt in the Roumanian structures is either Helvetian (Miocene), or Aquitanian (Oligocene). The writer feels that the possibility of Mesozoic age has not been given the consideration which the facts appear to warrant.

CONCLUSIONS

The amount of overburden above the mother salt series in the Emba basin is probably closer to the order of magnitude of overburden in the *interior* salt-dome province of Texas-Louisiana-Mississippi, and to that of the North German basin, than to that of the Gulf Coast.

The exceptionally large size of many of the central Emba shallow salt masses may be partly attributable to the relatively thin overburden in conjunction with a thick mother salt series. The differences in average size of intrusive salt masses in the various salt-dome provinces of the world are probably due to a combination of factors including the original thickness of the salt series, the thickness and character of the overburden, and the type or form of the structural anomaly which initiated salt flowage.

[37] This statement does not apply to the more normal salt domes, such as Floresti, and those of the Transylvanian district.

The salt domes of the Emba region constitute structural traps similar to those of the Gulf Coast, but the associated source beds for petroleum are evidently much less prolific and probably fewer in number than those of the Gulf Coast. Source beds in the Emba area, however, seem to be more prolific than those of the North German basin.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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RIDGE BASIN, CALIFORNIA[1]

J. EDMUND EATON[2]
Los Angeles, California

ABSTRACT

Ridge Basin is a graben dropped between the San Gabriel and the San Andreas faults as a result of local tension or differential pressure where the Garlock and the San Andreas rift faults meet and westward movement causes the latter to be bent into a great arc. Following the inception of the graben in or about Middle Miocene time its point sank with unprecedented rapidity, forming an inland lake in which 21,000 feet of Pliocene and Lower Pleistocene(?) sediments were deposited to comprise the thickest post-Miocene section in California.

Resting with marked unconformity on Eocene strata older than the basin is the basin sequence; reading upward, fragments of non-marine Mint Canyon (early Upper Miocene) yielding *Hipparion*, *Merychippus*, *Protohippus*, and *Parahippus*(?) near-by, then 2,000 feet of upper Monterey (late Upper Miocene) yielding a Neroly marine macrofauna at the base and grading upward to brackish strata, then 18,000 feet of Pliocene(?) lacustrine deposits more or less brackish at the bottom, and finally 3,000 ± feet of Lower Pleistocene(?) lacustrine beds.

The 23,000-foot post-Mint Canyon succession is continuously exposed as a northwest-plunging syncline between Castaic and Gorman, the axis of which is essentially the course of the new Ridge Route highway. The southwest edge of the succession is everywhere angular conglomerate deposited along the San Gabriel fault scarp. The conglomerate grades northeasterly to shale, which, in turn, grades back to pebbly sandstone farther northeast.

The vertical throw of the San Gabriel fault which bounds the basin on the southwest scissors near Castaic, and then increases from zero at the pivot to 23,000 ± feet 20 miles northwest. The particular throw occurred between Middle Miocene and Middle Pleistocene times concomitant with deposition. Following this extreme activity the deep-seated fault plane froze, and has now been essentially dead for a million or so years between Castaic and Beartrap Canyon.

After deposition ceased the basin was deformed and degraded approximately 15,000 feet in the Coast Range revolution of Middle and Upper Pleistocene time. During this interval crystalline Frazier Mountain was dragged or thrust across the extreme northwest point of the basin from an original site computed to have been east of the junction of the Garlock and San Andreas rift faults, thus causing piracy of drainage systems to occur on a grand scale, and giving to Piru Creek its present anomalous upper course.

INTRODUCTION AND ACKNOWLEDGMENT

For a distance of 20 miles between the towns of Castaic and Gorman, geologists travelling the new Ridge Route, U. S. Highway 99, pass along the well exposed, plunging axis of the finest post-Miocene lacustrine section in California, and perhaps in the world. Starting with 2,000 feet of uppermost Miocene marine and brackish strata at the base, the section then passes upward into and through 21,000 feet of Pliocene and Lower Pleistocene(?) fresh-water beds indicated to be an equivalent of the 20,000-foot marine section of these ages in the adjacent Ventura Basin. Peculiarly, this section, seen by more geologists, and more often by these, than any other in California, is publicly one of the least known in the state. The only publication

[1] Manuscript received, January 26, 1939.

[2] Consulting geologist, 2062 North Sycamore Avenue.

including it of which the writer is aware is one by Clements,[3] and in this short, valuable discussion of a wider area the particular section is necessarily but briefly mentioned.

Thirteen years prior to the present writing the writer made a rapid reconnaissance of Ridge Basin and secured most of the data presented herein. He verbally informed various geologists of these, but published nothing on the basin except to name it and make brief reference to an aspect of gradation there in connection with a broader problem.[4] An outline of the general geology is here presented to assist future, detailed workers in organizing their special investigations, and perhaps to make a monotonous 30-mile drive by hundreds of geologists more interesting.

The writer is indebted to H. B. Rathwell who accompanied him on early trips, to G. H. Doane, P. P. Goudkoff, Boris Laiming, and W. D. Rankin for micropaleontological determinations, to U. S. Grant and E. H. Quayle for macropaleontological data, and to J. H. Maxson, R. A. Stirton, and Chester Stock for vertebrate evidence on adjacent territory. Publications by Buwalda, Gazin, and Sutherland,[5] by Clements,[6] and by Kew[7] have been of value. H. B. Allen kindly photographed the distant views especially for the paper.

STRUCTURAL HISTORY

Figure 1 illustrates the origin and existence of Ridge Basin as the depressed northwest point of a triangle faulted down between the San Andreas and the San Gabriel faults, which point progressively changed its direction of tilt from southwest, to west, and finally to northwest, thereby acquiring enormous thicknesses of sediments, chiefly lacustrine, along its more sunken edge. Before discussing the basin it seems advisable to review briefly the history and nature of the bounding primary faults.

San Andreas rift fault.—This, the master shear or line of maximum horizontal adjustment in coastal California, runs diagonally southeast across much of the state to and beyond Yuma, Arizona. Since its

[3] Thomas Clements, "Structure of Southeastern Part of Tejon Quadrangle, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 2 (February, 1937), pp. 212–32.

[4] J. E. Eaton, "The By-Passing and Discontinuous Deposition of Sedimentary Materials," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), Fig. 5, and footnote, p. 750.

[5] J. P. Buwalda, C. L. Gazin, and J. C. Sutherland, "Frazier Mountain, a Crystalline Overthrust Slab, West of Tejon Pass, California," *Pan-Amer. Geologist*, Vol. 54, No. 1 (August, 1930), pp. 71–72.

[6] *Op. cit.*

[7] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924).

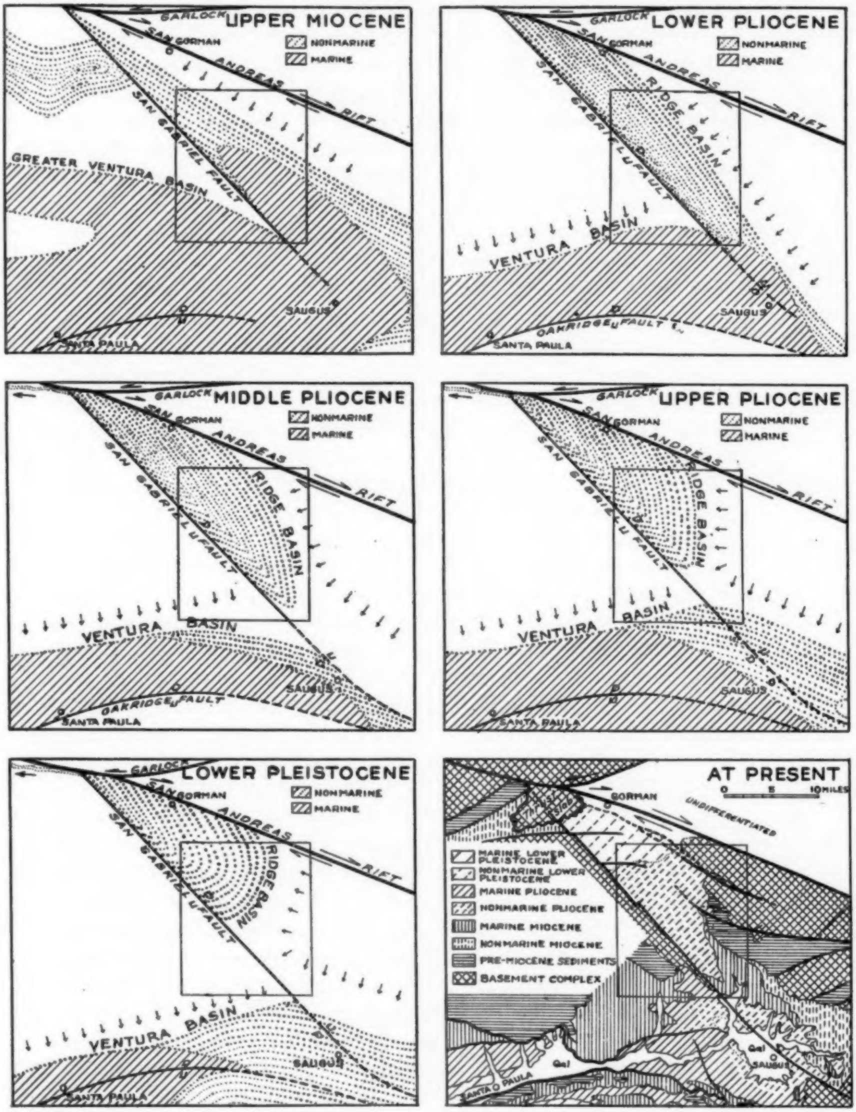

FIG. 1.—Ridge Basin and adjacent territory at various stages. Arrows indicate apparent direction of tilting. Small rectangle outlines Fig. 2.

unmapped ends extend into the Pacific Ocean on the one hand and into Mexico on the other, its total length is unknown. In this connection, however, the horizontal throw, indicated to be largest near the great bend near its mapped center, appears to diminish toward the ends, and southeast of San Bernardino and northwest of San Benito is distributed among branches to such an extent that the singular unity so characteristic of the more central stretches in part disappears. This division of the total throw among branches toward the ends, with its attendant decrease in single magnitude, causes the shear, ruthlessly straight in strike for long stretches near its center, to become toward the ends a less powerful feature which swerves here and there under various influences that would be relatively ineffective nearer its center. It shows that the rift is not, as some might suppose, a transcendent visitor which merely passes through California, but is a local phenomenon in part determined by some local cause, as might be inferred from the feature that its peculiarly dominating magnitude is seemingly not duplicated in adjoining provinces.

The rift is now bent far to the southwest at a point opposite the southern end of the Sierra Nevada. This bend is not a single arc, as old maps show, the fault trace bending in a double arc which suggests that the bend is not an original course but is a subsequent dent. Since resistance to horizontal slippage increases with the slightest deviation from a straight line, the rift would tend to take a relatively straight course at the start, as is evident from its long, straight stretches, and any subsequent bends would tend to be acquired. The amount of crustal shortening in coastal California southwest of the rift closely parallels the amount to which the rift now departs from a straight line, thus showing pressure from the northeast and a cause from that direction. This line of evidence is developed elsewhere.[8]

The approximate amount of horizontal throw along the San Andreas rift fault can be determined at various points. The largest observed amount occurs just northwest of its major bend, where, in and near Carrizo Plain, 100 square miles of coarse, nonmarine upper Miocene sediments are now surrounded by finer-grained marine sediments of equivalent age, with, therefore, apparently no possible source. If these are moved by the eye southeastward a distance of approximately 25 miles they parallel the San Emigdio Mountains, seemingly the only possible source for them, indicating a total post-Miocene horizontal throw here along the rift of this amount.

The magnitude of the intersecting Garlock rift fault, though be-

[8] J. E. Eaton, "Decline of Great Basin, Southwestern United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 1 (January, 1932).

coming better known, is probably still underestimated by geologists. This is the only rift that the San Andreas, which to all appearances is unaffected by the 4 miles of vertical throw brought it by the San Gabriel fault, defers to in its central, more ruthless part. At its junction with the Garlock rift the San Andreas rift swerves sharply. More significant is the great bend in the San Andreas rift extending northwest and southeast of the meeting place. Hulin,[9] who first recognized the magnitude of the Garlock rift, reports 5 miles of horizontal throw along it, chiefly Quaternary, with the north side moving relatively west. As his measurement was made 85 miles east of the junction it presumably represents a smaller throw than that present at the western culmination.

The history of Ridge Basin, its origin, development, and decline, is bound up with the history of the San Andreas and the Garlock rifts, for these rifts were the parents of the San Gabriel fault, which, in turn, determined the basin. The Garlock rift was obviously the instigator of the sequence, for the basin occurs near the turbulent junction of the Garlock and the San Andreas and was later the recipient of a huge overthrust crystalline slab from this violent meeting place of the two giants.

San Gabriel fault.—The San Gabriel fault was originally mapped and named by Kew[10] in the San Gabriel Mountains southeast of Ridge Basin. Kew's field work did not extend into the latter area. In 1925 the writer traced this fault (Fig. 2) to and through Ridge Basin. The fault is clearly an offshoot of the San Andreas rift. Branching from the latter (at a point now west of Tejon Pass but originally east of this), it extends 90 miles or more southeast, locally bent by thrusting from the northeast. It scissors near Castaic. Starting from this point its ancient vertical throw increases from nothing at the pivot to a figure in excess of 4 miles where it joins the great rift. There is some evidence southeast of Ridge Basin that the San Gabriel fault has a horizontal component in its throw of several miles. The feature that it crosses and bounds three basins, and particularly its repeated scissoring, are indicative of a marked horizontal component. However, as the writer has not measured this in Ridge Basin, further discussion will chiefly have to do with the known vertical throw, which, as stated, is locally in excess of 4 miles. In Ridge Basin the fault plane, where observed, now dips northeast at angles between 50° and 80°. Discounting surface variations, the deep-seated dip is probably somewhat uniformly an angle between 60° and 70°.

[9] C. D. Hulin, "Geology and Ore Deposits of the Randsburg Quadrangle, California," *California State Min. Bur. Bull. 95* (1925), pp. 63, 64, 68.

[10] *Op. cit.*

The circumstance that the oldest exposed sediments, Upper Miocene, along the southwest side of Ridge Basin, grade to angular conglomerate in a paralleling straight belt along the fault trace indicates that the San Gabriel fault was active at least as early as Upper Miocene. The inception of the large Oak Ridge fault which bounds the adjacent Ventura Basin proper on the south is known to have been in or about Middle Miocene time, for the sediments older than this are conformable and of equally great thickness on both sides, whereas those younger are conformably developed to an enormous thickness north of it and are but thin veneers separated by major unconformities south of it, with uppermost Miocene locally resting on lowermost Miocene, and the Lower and Middle Pliocene entirely absent. Since the strikes of the Oak Ridge and San Gabriel faults intersect, and strains set up or relieved in the one territory should have been felt in the other, the two fractures may have originated about the same time; that is, Middle Miocene. However this may be, the San Gabriel fault was active in Upper Miocene time. From the evidence of the sedimentation in Ridge Basin its activity increased to a maximum during the Pliocene, decreased in the Lower(?) Pleistocene, and then practically ceased. Reasons will later be given for believing that the San Gabriel fault has been essentially dead, as regards a vertical component, for a million or more years between Castaic and Beartrap Canyon.

Origin and development of Ridge Basin.—Figure 1 picks up the history of Ridge Basin at its earliest known time, Upper Miocene. Prior to this the Eocene series was deposited in an east-west seaway across the site of the subsequent basin. The Oligocene and Lower and Middle Miocene series are not exposed in Ridge Basin, and from regional considerations are probably largely or wholly absent there, but they are present in Ventura Basin on the southwest. Their thinning edges once extended northeastward almost to the San Gabriel fault, but apparently disappeared before reaching this line.

The precise nature and action of the forces operating to cause the triangular graben whose northwestern point comprises Ridge Basin to sink to almost incredible depths in post-Miocene time are not known. Features and relations are nevertheless present which enable an observer to infer the immediate cause and mechanics, and to feel that if the inferred mechanics were not the actual ones they at least approximate the latter.

First, the critical point of the Ridge Basin graben occurs near where the Garlock rift, the only fault to swerve the San Andreas rift in its strong center part, meets the latter. The point of the graben

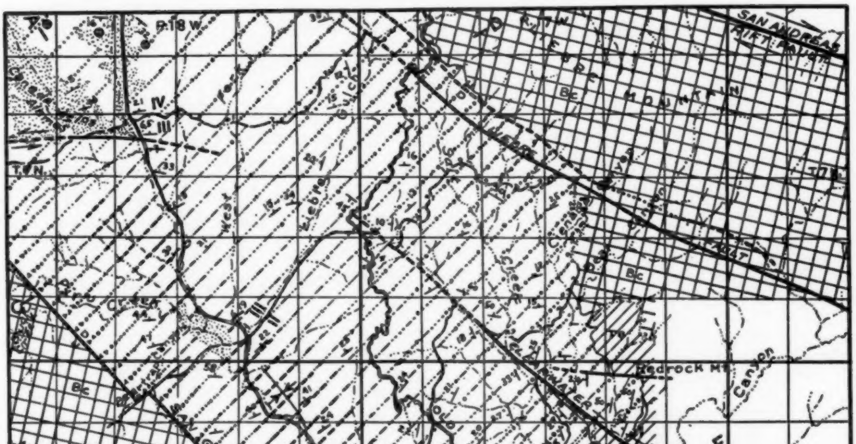
RIDGE BASIN, CALIFORNIA
CG
SS
SS & SILT
SHALE
ALL TEXTURES
BROKEN LINES NONMARINE
SOLID LINES MARINE
ALLUVIUM
IV–LOWER PLEISTOCENE(?)
I,II,III–PLIOCENE(?)
UPPER MIOCENE
LOWER EOCENE
BASEMENT COMPLEX (CHIEFLY GRANITE)
UNDIFFERENTIATED
WELL DRILLED FOR OIL
0 1 2 3 4 MILES
BASE FROM TEJON QUADRANGLE, U.S.G.S.
J.E. EATON, 1938
SAN ANDREAS RIFT
Redrock Mt.
Canyon
FAULT
Oak Flat
T.6N.
T.7N.
R.18 W.

FIG. 2

is now northwest of the meeting place, but prior to horizontal displacement it was apparently southeast of this.[11] Second, the graben occurs near the maximum bend in the San Andreas rift, which bending caused intense shortening and overthrusting in the sediments between it and the coast that decreases northwest and southeast from this bend. The parallel ratio between the amount of bend and the amount of shortening is evidence tending to show that pressure directed southwestward caused the bend. Third, the reported amount that the territory north of the Garlock rift has *slipped* along this rift (in its much greater movement of tens of miles westward) is approximately the amount that the strike of the San Andreas rift now departs northwest of Tejon Pass from the strike that it has when it approaches this pass.

The greater and general westward movement causing the outward bend in the San Andreas rift produced compression whose magnitude can be realized only by those geologists who have mapped the great series of south- and southwest-riding overthrusts that extends 50 miles in these directions. The pressure of the northern mass moving westward along the Garlock rift should set up unequal pressures in the relatively noncompressible basement. The differential would tend to create a potential void south from Tejon Pass between the San Andreas rift and some western area where the pressures would become areally more nearly equalized by diffusion of compression from the great bend in the San Andreas. A local tension fault similar to the San Gabriel would be indicated, with a dropped triangle between rift and tension fault. The point of such a triangle, being at the maximum of tension, should drop most rapidly. At some future time when horizontal movement along the San Andreas rift moved the point of the falling triangle northwest of the Garlock rift the fall of the triangle would be slowed; when moved far enough past this rift to encounter the primary compression being exerted westward the deep-seated plane of the tension fault would freeze, and the falling point of the triangle would be held and locked.

The known facts are that Ridge Basin, the deepest graben in coastal California, occurs where the largest rift fault in California comes in conflict with the next largest rift fault. Its point sank 23,000 feet during Upper Miocene, Pliocene, and Lower Pleistocene(?) time along the bounding San Gabriel fault, which later froze, and has been essentially dead for a million or more years. Whether the hypothesis

[11] Figure 1, to avoid geographical confusion, does not show this movement. The point of Ridge Basin should be shown as east of the junction of the two rifts in the Upper Miocene, and then progressively moving past this junction to its present position west of it.

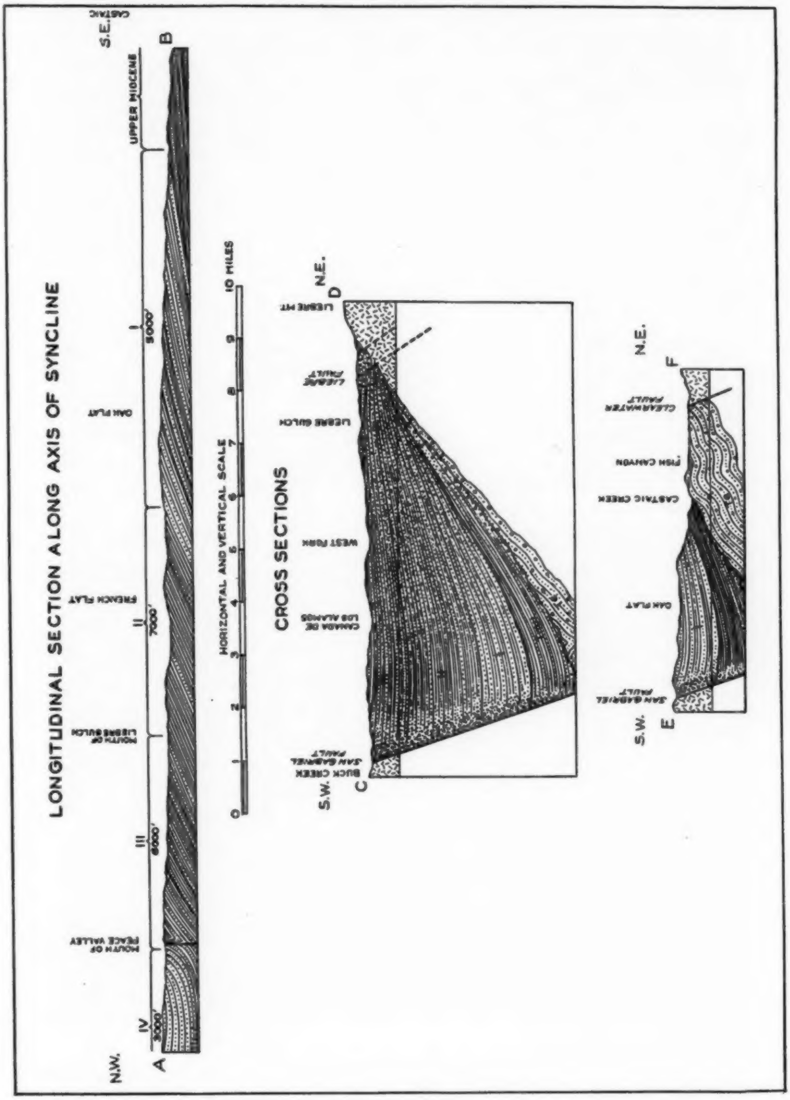
LONGITUDINAL SECTION ALONG AXIS OF SYNCLINE
N.W.
A
S.E.
B
CASTAIC
UPPER MIOCENE
I
5000'
OAK FLAT
FRENCH FLAT
II
7000'
MOUTH OF LIEBRE GULCH
III
6000'
MOUTH OF PEACE VALLEY
IV
3000'
HORIZONTAL AND VERTICAL SCALE
10 MILES
CROSS SECTIONS
S.W.
C
N.E.
D
BUCK CREEK
SAN GABRIEL FAULT
CANADA DE LOS ALAMOS
WEST FORK
LIEBRE GULCH
LIEBRE FAULT
LIEBRE MT.
S.W.
E
N.E.
F
SAN GABRIEL FAULT
OAK FLAT
CASTAIC CREEK
FISH CANYON
CLEARWATER FAULT

FIG. 3

presented for its origin, development, and quiescence is close to or far from the actual mechanics, it should at least convey some idea of the large forces acting, which were entirely competent to produce this remarkable basin.

Tilting of the basin.—That the basin had a tilt which progressively changed in direction from southwesterly in the Upper Miocene to northwesterly in the Lower Pleistocene(?) is evidenced by the sedimentation which occurred. Thus, the Upper Miocene thickens more or less directly toward the San Gabriel fault, and the divisions above this each thicken at a slightly lesser angle to the fault, with the uppermost one thickening almost parallel to it. In other words direction of tilting progressively rotated clockwise. One result of this phenomenon was to cause the younger divisions to extend farther up the northeast flank than older ones, the older being progressively overlapped by the younger, which successively make contact with the underlying granite on this flank (Fig. 2).

If the original direction of tilt had persisted the degradation subsequent to deposition would have amounted to 23,000 feet in Middle and Upper Pleistocene time, since the base of a consecutive section of this thickness is now exposed and erosion could not have started until deposition ceased. Due to the rotating direction of tilt, however, the total degradation can be as little as 16,000 feet, for differential tilting resulted in successively thinner deposition on the southeast, and may have caused emergence and erosion of the base to be contemporaneous with the later deposition. Considering that the base of a 20,000-foot conformable section the upper part of which is marine Lower Pleistocene is now exposed in middle Ventura Basin, and that over wide areas in coastal California sediments were degraded from 5,000 to 7,000 feet during the high emergence of Middle and Upper Pleistocene time, neither the minimum nor the maximum figures for degradation in mountainous Ridge Basin are particularly noteworthy.

AREAL GRADATION OF THE SEDIMENTS

Areal gradation of individual divisions is discussed later under the heading of stratigraphy, but the general feature, which was controlled by structure, seems best described in connection with the latter. Figures 2 and 3, and a comparison of the various photographs, illustrate the phenomenon graphically, and leave only connective data to the text.

Southwestern flank.—Deposition along the southwestern strand was not of a normal type, but took place against the bounding San Gabriel fault scarp. All horizons observed by the writer in the 23,000-

FIG. 4.—*Above:* San Gabriel fault where this crosses road to Whitaker Peak. Granite (white) on the left. On right (darker) is fault zone, here about 200 feet thick, composed of broken gneiss, then highly slickensided and formless igneous-sedimentary mixture, and finally crushed, angular granitic cobbles. *Below:* Reddish conglomerate of First Division a few hundred feet northeast (basinward) from the foregoing, composed of angular granitic cobbles.

foot section (the upper 3,000 feet have not been examined by him on this extreme flank) end abruptly at the fault scarp. There was no appreciable flank later cut off by subsequent movement; the fault scarp was essentially the edge of deposition. The thickest section in the basin occurs at or near the ancient scarp. It consists wherever examined of a nearly shapeless mass of cobbles or boulders, chiefly granitic in composition, and generally angular or subangular as if the material had fallen or been dumped near where it now lies with a minimum of reworking and wear. This refers to the immediate vicinity of the fault. Within a few hundred feet basinward the average conglomerate tends to become less coarse, and bedding planes to appear (Fig. 4). At a distance of about 1,000 feet from the fault only occasional pebbly lenses remain, and the section has graded to well bedded sandstone and silt. In a distance of less than one mile from the San Gabriel fault most of the post-Miocene part grades to lacustrine shale having the monotonously even, perfect, and persistent bedding characteristic of such still-water deposits.

The belt of finest texture occurs about one mile from the fault (a little more in the upper part of the section), and beyond that belt the sediments become increasingly coarse toward the northeastern flank. This belt coincides somewhat closely with the present synclinal axis, indicating that this axis is a primary feature that has been followed and deepened by the deformation subsequent to deposition; that is, the short southwestern flank appears to have been a drag effect against the San Gabriel fault scarp, and the initial lead was followed by the later folding.

The exposed conglomerate along the fault begins as a narrow strip more than 100 feet wide in the Upper Miocene series, and at first widens slowly. At the mapped contact with the Pliocene it widens within a short distance to about 1,000 feet. From here on there is a gradual and almost imperceptible widening northwestward. At first glance this might seem to denote a fault scarp becoming higher with time. The sharp widening of the band near the Miocene-Pliocene(?) contact may represent a growing scarp. The more gradual widening farther northwest is considered more likely to represent not a growing scarp but a persistently higher one due to the known wider granitic flank there.

The contact between the conglomeratic band and the paralleling fine sediments deposited chiefly from suspension and solution is so abrupt and straight that it locally gives the impression of a fault line. This effect is intensified by the dark reddish color of the conglomerate contrasted with the lighter color of the paralleling shales, and a tend-

ency of the latter to slump away from the former and to be eroded more rapidly. Local surface fracturing has taken place along this contact, but the many places where the sediments can be seen to grade unbroken from the San Gabriel fault to the synclinal center precludes there being any continuous or important fault between the conglomerate and the finer sediment. The sedimentation is that of a conspicuous gradation from a wall-like strand to paralleling deep and quiet waters a few hundred yards offshore.

Northeastern flank.—Gradation northeastward from shales at the synclinal center to coarser material is at the beginning almost as marked as that on the southwestern flank. Within a mile or so the shales grade to pebbly sandstones separated by thin silty partings. From here on the gradation does not continue so markedly and progressively to conglomerate as it does on the opposite flank, but takes place more gradually, the pebbly sandstone facies continuing as a rule for a mile or two before persistent conglomerate is reached. This is understandable through the circumstance that during deposition on this more gently sloping flank shallow-water waves and currents operated to spread the coarser detritus through pseudomarine mechanics, as is shown by the less continuous bedding, the cross-bedding, and the numerous diastems. As it neared the synclinal center the broad, gently sloping bottom steepened, shallow-water waves and currents became ineffective, and within a short distance deposition of muds and calcium carbonate from suspension and solution occurred.

A critical belt is thus present on each flank between a strandward band of traction-laid material and the central band where deposition occurred from suspension and solution. On the southwest flank, which had a steeply sloping bottom, this belt is so narrow—but a few hundred feet in width—that, as mentioned, it conveys the aspect of a fault between the conglomerate and the shale. On the northeast flank, with its gently sloping bottom, the critical belt has a width of several thousand feet.

Persistent conglomerates on the northeast flank, where these are finally reached after the generally broad stretch of pebbly sandstones, are found to be of a normal type in contrast to those on the opposite flank, as Clements observed. The pebbles and cobbles, composed chiefly of granite, gneiss, and various metamorphic materials, are well rounded and worn, being apparently stream detritus brought in part from a distance. Isolated rounded boulders, some of them several feet in diameter, occur locally in lenses. In lower parts of the section the finer members alternate with coarser members relatively far strandward, and the final transition to conglomerate is delayed and is

fairly abrupt. In upper parts of the section the coarsening to conglomerate is more gradual, and boulders and large cobbles are relatively rare even near the strand.

It is apparent from the short detrital flank on the southwest and the much longer one on the northeast that the bulk of the visible material came from the northeast (see Section *C–D*, Fig. 3) as regards all but the uppermost division. The latter appears to have received a larger contribution from the southwest. It seems probable that toward the northwest all divisions of the section received an increasing proportion of their materials from the southwest.

Outlet of Ridge Lake.—The upper 16,000 feet, at least, of the section is purely lacustrine, as is shown not only by a characteristic bedding, gradation, and composition of the sediments, but also by the practically continuous occurrence of fresh-water ostracods. The absence of any observed large concentration of salts, and the occasional deposition of thick sand members entirely across the basin, show that the lake had either a persistent or an intermittent outlet during its entire existence through which at most times some, and occasionally nearly all, of the received finer material was lost. Evidence tending to show that this outlet must seemingly have been on the northwest is given under another heading, a conclusion which might be inferred from the later directions of tilt. The outlet could have led to what is now Cuyama Valley, San Joaquin Valley, or the Great Basin, the first mentioned seeming the most likely from the feature that it is the only route that would not necessarily have to cross the disturbed line of the San Andreas rift (across which few modern streams can maintain a channel), as well as from other relations.

The occasional deposition near the middle of the section of sandstones from 50 to 150 feet thick entirely across the basin sandwiched between 1,000 or more feet of shale below and above gives rise to an unsolved problem. Such a feature clearly records an almost complete loss of the finer materials through an outlet for a period of thousands of years; a loss abruptly begun, and as abruptly ended. For the causative mechanics, on the other hand, no satisfactory explanation has been found. The writer has considered the following possibilities: (1) occasional delayed slippage along the San Gabriel fault, which first would shallow the lake, and, with renewed movement, would deepen it; (2) occasional cycles of greatly increased erosion, which might cause the flanking, traction-laid belts to be extended and to meet; (3) increase of outflow where this crossed the San Gabriel fault or San Andreas rift by fault slippage, with subsequent return to a normal outflow; (4) cycles of deeper wave or current action which would

shift or spread traction-laid sediment more widely, and prohibit settling from suspension and solution. The first hypothesis seems consistent with the abrupt termination of coarse sheet deposition, but not with its abrupt inception. The second seems consistent with neither, due to a storage factor which would delay both the appearance and disappearance of its effects basinward. The third appears unlikely because slippage would more likely decrease the outflow than increase it. The fourth appears consistent with both the abrupt inception and termination of coarse sheet deposition, but it is difficult to conceive of the origin and persistence through thousands of years of such strong waves and currents in a lake.

Although the writer has mentioned certain variations, the way in which Ridge Lake maintained roughly the same area for deposition, the same strand lines, the same textures vertically, and particularly the same boundary between textural belts for millions of years seems remarkable. Durations of more than one lifetime can only be words to us. One lifetime is the largest actual measuring rod known, and is our real conception of eternity. For the unchanging sea and the everlasting hills legend prepares us before we ever hear of geology and change. But for a little lake to maintain essentially the same appearance and arrangments for more than a hundred-thousand lifetimes seems unreasonable when a busy highway built across its site with all the ingenuity of man disintegrates in a few seasons after being abandoned. The inconceivable slowness, from our scale of reckoning, with which nature operates in the geologic cycle and changes major physical outlines, basic organic structure, and instincts, is beyond human yard sticks.

STRATIGRAPHY

Table I shows post-Oligocene stratigraphic columns for Ridge Basin, for easternmost Ventura Basin defined as the portion of this basin northeast of the San Gabriel fault, and for middle Ventura Basin defined as the part of this basin proper lying west of Sespe Creek, east of Rincon Point, and north of the Oak Ridge fault. The figures given are for the maximum sections measured and degradations indicated.

EOCENE

The oldest known unmetamorphosed sediments exposed near Ridge Basin are of Eocene age, possibly in part older, deposited prior to the inception of the basin in an east-west seaway across its site. This series has been examined in detail by the writer only along its contact with the overlying Miocene, inspection of the main body

having been confined to two traverses through it. The section east of Ridge Basin comprises several thousand feet of highly indurated, well cemented conglomerate and sandstone with one or more silty members. The upper part is better bedded and less deformed than the lower, suggesting that two divisions of the Eocene, or the Eocene

TABLE I

	Ridge Basin	*Easternmost Ventura Basin*	*Middle Ventura Basin*
PLEISTOCENE	Middle and Upper: deformation and 15,000 feet ± of degradation Lower: 3,000 feet ± of lacustrine beds (Fourth Division)	Middle and Upper: deformation and 12,000 feet ± of degradation Lower: some non-marine upper Saugus, now removed	Middle and Upper: deformation and 15,000 feet ± of degradation Lower: 1,800 feet of marine Hall Canyon, brackish at top. 2,550 feet of marine San Pedro
PLIOCENE	18,000 feet of non-marine beds. Upper 13,000 feet lacustrine (Third and Second divisions). Lower 5,000 feet more or less brackish (First Division)	2,000 feet ± of non-marine Saugus (Upper Pliocene) subsequent to Middle and Lower Pliocene interval of erosion strandward and thin deposition(?) basinward	15,450 feet of marine strata
MIOCENE	Upper: 2,000 feet of marine and brackish Neroly (uppermost Monterey) above thin fragment of non-marine Mint Canyon Middle and Lower: hiatus on east; status unexposed on west	Upper: 2,000 feet of marine and brackish Neroly (uppermost Monterey) overlying 4,000 feet ± of non-marine Mint Canyon yielding *Hipparion*, *Merychippus*, *Protohippus*, and *Parahippus*(?) in its upper third Middle and Lower: 8,000 feet ± of undifferentiated non-marine beds. Probably includes some Oligocene	Upper: 4,000 feet of marine Monterey Middle and Lower: 5,000 feet of marine Temblor and Vaqueros

and an older series, may be represented in the whole. Clements[12] reports Martinez (Lower Eocene) fossils from a part of the sequence.

MIOCENE

Although a thick and almost or quite complete marine Miocene series is locally present in western and middle parts of the adjacent Ventura Basin, only Upper Miocene seas extended into the easternmost part of this basin and Ridge Basin. Since Ridge Basin was

[12] *Op. cit.*, p. 214.

connected with and was an extension of easternmost Ventura Basin in the Upper Miocene (Fig. 1), relations in the latter will first be described.

Easternmost Ventura Basin.—This was the site during much of Oligocene(?) and Miocene time of continental deposition which according to Kew[13] approximated 12,000 feet in thickness if associated basic flows are included. The lower and larger part of the continental sequence, which has so far yielded no faunas, is sometimes tentatively referred to as Sespe(?) but may include nonmarine equivalents of marine Lower and Middle Miocene horizons which are present farther west. The upper several thousand feet, the Mint Canyon formation, has yielded mammalian faunas.

The Mint Canyon continental beds underlie at least 2,000 feet of marine and brackish sediments which contain the best late Upper Miocene marine invertebrate fauna in southern California. According to the marine column for the state the age of the Mint Canyon beds would therefore approximate early Upper Miocene. However, their fauna includes the equid genus *Hipparion*,[14] previously considered to be confined to the Pliocene. This has given rise to controversy. Maxson,[15] holding that the precise age of European beds which are the type for *Hipparion* is disputable, considers the relations at Mint Canyon to indicate existence of the genus in the Upper Miocene. Stirton,[16] on the other hand, believing that the range of the genus has been sufficiently established as Pliocene to allow it to be used as a guide, would call the Mint Canyon beds Lower Pliocene. Stock[17] comments as follows.

> Considerable discussion has arisen as to the time of origin of the genus *Hipparion*, although all are agreed that this horse evolved from the antecedent merychippine group. The origin of *Hipparion* seems most likely to have occurred in America and since the occurrence of the genus in the Old World is Pontian or even pre-Pontian, according to some authors, we cannot ignore the possibility of time of origin of *Hipparion* in the New World in the latest Miocene or in the transitional period from Miocene to Pliocene.

[13] *Op. cit.*, Pl. 3 and p. 39.

[14] J. H. Maxson, "A Tertiary Mammalian Fauna from the Mint Canyon Formation of Southern California," *Carnegie Inst. Washington Pub. 404* (1930), pp. 77–112. (This publication is the source for the mammalian genera listed in Table I and in the abstract of the present paper.)

[15] J. H. Maxson, "Miocene-Pliocene Boundary," a paper read before the Pacific Section, *Amer. Assoc. Petrol. Geol.*, at Los Angeles, November 4, 1938.

[16] R. A. Stirton, "Significance of Tertiary Mammalian Faunas in Holarctic Correlation," a paper read before the Pacific Section, *Amer. Assoc. Petrol. Geol.*, at Los Angeles, November 4, 1938.

[17] Chester Stock, letter to the writer, dated December 28, 1938.

The present writer would call attention to the feature that most of those boundaries between epochs and periods, including the one in dispute, which have been based on the marine invertebrate record in California, also correspond to epeirogenic boundaries in time which are indicated to have more than provincial significance. The present paper follows the marine column for California because its 50,000-foot Cenozoic succession affords the most complete known record for this era, whereas the known continental record is fragmentary.

Above the Mint Canyon continental beds, as mentioned, at least 2,000 feet of late Upper Miocene marine and brackish strata occur in easternmost Ventura Basin. This marine sequence yields a fauna near its base reported[18] to include *Astrodapsis* resembling *tumidus*, *Ostrea titan*, *Pecten crassicardo*, *P. discus*, *P. estrellanus*, and *P. raymondi*. This is an Upper Miocene assemblage, the two species first listed indicating Neroly age, the highest macrofaunal division in the marine Miocene of California.

Ridge Basin.—The Mint Canyon beds die out toward Ridge Basin by a successive loss of basal parts, but their upper, fossiliferous part is exposed in small areas near its southeast corner. The overlying marine and brackish Upper Miocene described extends northwestward into Ridge Basin as a narrowing band along Castaic Creek (Fig. 2) between Mint Canyon and Eocene below and Pliocene(?) above, to be overlapped finally by the latter near Red Mountain. The northward disappearance seems to occur partly as a result of successively higher Miocene beds resting on the Eocene, and, possibly, from successively lower beds being in contact with the Pliocene(?). Available data are insufficient to determine which of these is the larger factor. The contact with the Eocene below is highly unconformable, with locally 20° or more difference in dip and strike. It is well exposed in various canyons, the most accessible clear exposure being the west bank of Castaic Creek a few hundred yards north of the junction of this creek with Fish Canyon.

The average aspect for the Upper Miocene is an unfossiliferous basal conglomerate, ranging from a few feet to several hundred feet in thickness according to old headlands and inlets, which rests upon the Eocene and in poor exposures so resembles the latter that the two successions may be confused. Above this is generally a reef several feet thick composed largely of *Ostrea titan* shells. A little higher are silty sands containing most or all of the marine species listed previously from easternmost Ventura Basin. The occurrence of the fauna

[18] Miscellaneous determinations by B. L. Clark, U. S. Grant, L. G. Hertlein, and W. P. Woodring.

is spotted, some canyons being almost barren and others yielding abundant, well preserved specimens. The section quickly passes upward into barren buff sandstone and chocolate silty sand, and finally into a thousand feet or more of thin-bedded chocolate silty sand carrying some sandstones. The proportion of sandstone varies areally according to the distance from a strand, as do several medium to heavy-bedded, ridge-forming gray to buff members. North from Fish Canyon the whole grades to pebbly, submassive buff sandstone with thin layers of chocolate sand.

FIG. 5.—Upper Miocene sandstone and bluish black silt. New Ridge Route highway, a little southwest of synclinal axis. About 1,000 feet below top of local Miocene.

Silt samples collected a few hundred feet above the base in Necktie Canyon and also two miles north of Castaic are reported by W. D. Rankin to contain a sparse foraminiferal fauna which would fit in the upper, diatomite part of the section near Girard, or possibly higher; that is, a horizon not far from the top of the Miocene. The 1,700 feet of the sequence which lies above these (Fig. 5) carries wood fragments and appears to be largely of brackish-water origin. Two samples from essentially the same horizon determined by Rankin, but secured on the new Ridge Route highway 2 miles northwest of Castaic just below the apparently brackish upper member, are re-reported by Boris Laiming to contain a somewhat provincial foraminiferal fauna indicating a horizon high in the Miocene. They

include one or more foraminiferal species which range from the Upper Miocene into the Pliocene, and ornate ostracods.

On the basis of these various faunas, molluscan and foraminiferal, the marine portion of the sequence is late Upper Miocene. The 1,700 feet of apparently brackish beds which grade up from the marine strata are not certainly Miocene, but since these and the underlying marine strata seem to be parts of one unit they are treated as representing the highest horizon of this epoch.

Southwest of the new Ridge Route, U. S. Highway 99, the Upper Miocene series, like all strata exposed on that side of the basin, grades to conglomerate against the San Gabriel fault. The series is absent immediately across the fault, the Pliocene series there lying on a granitic basement.

PLIOCENE(?)

Resting on the foregoing series with a change in depositional conditions is a succession, entirely or chiefly lacustrine, approximately 21,000 feet in thickness exposed along the axis of the Ridge Basin syncline. From the relations mentioned all of this should be post-Miocene in age. There are reasons to believe that it may be a non-marine equivalent of the 20,000-foot marine section of Pliocene and Lower Pleistocene age in middle Ventura Basin. The lower 18,000 feet of this succession in Ridge Basin, essentially a depositional unit, is tentatively correlated with the 15,450 feet of marine Pliocene in Ventura Basin. The upper 3,000 feet, also a unit, is tentatively correlated with the 4,350 feet of marine and brackish Lower Pleistocene in the latter basin. Until the fresh-water and mammalian faunas of the succession have been studied the ages tentatively assigned those units and sub-units in Ridge Basin above the uppermost Miocene unit and below the regional uplift in California elsewhere dated as Middle and Upper Pleistocene must bear question marks.

The contact of the 21,000-foot overlying succession with the underlying Upper Miocene may or may not be unconformable. The writer has not examined the contact in detail. The change in deposition between the Upper Miocene below and the 18,000-foot Pliocene (?) unit above is, in general, though not everywhere, so marked and uniform a horizon that it can generally be followed for miles by the eye. On the other hand, there are local stretches, notably west of Fish Canyon, at which place the basal Pliocene (?) contains brown silty sands not unlike those of the Upper Miocene, where to map the contact closer than several hundred feet would require detailed work (Fig. 6).

FIG. 6.—*Above:* Flank view looking north up Castaic Creek near its junction with Fish Canyon. Liebre Mountain, granite, in far distance. Very ragged cliffs on right, nearer distance, are those of Red Mountain, Granite. Right of main canyon is Eocene, which crosses canyon to form bare part of isolated hill this side of Red Mountain. Upper Miocene overlaps Eocene as bare, silty band left of hill mentioned, with its basal conglomerate forming brush-covered top of hill. Thick section above bare Upper Miocene is sandstone forming lower part of First Division. Exception: well bedded white sandstone on right of main canyon and this side of Red Mountain is base of First Division horizontally offset by Clearwater fault 2 miles from its proper site (see Fig. 2). *Below:* Flank view looking north by northwest at continuation, upward, of foregoing section. Liebre Mountain in far distance, right. Clearwater fault lies just beyond isolated, steeply dipping hill on right, middle distance, whose strata have been tilted and cemented along it. Fault strikes toward notch at right of high ridge (Reservoir Hill) on left. This side of fault is almost complete (thin strandward) pebbly section of First Division, excluding high ridge on left. This high ridge exposes pebbly (strandward) sandstone of Second Division, as does region beyond fault which is horizontally offset to right by fault an undetermined distance.

On the northeast flank of Ridge Basin the entire 18,000 feet of Pliocene(?) grades to monotonous pebbly sandstone, and on the southwest flank, against the San Gabriel fault, to even more monotonous reddish conglomerate. In the central syncline things are different. Here, the Pliocene(?) unit can be divided into three readily distinguishable divisions, with an overlying fourth division tentatively assigned to the Lower Pleistocene. The four divisions mentioned will be described as they exist along the synclinal axis, which approximates the route of the new U. S. Highway 99, with the understanding that all thicknesses and aspects mentioned, except when comparisons are made, refer to conditions along this axis and highway.

First Division (*Lower Pliocene*?).—This comprises the lower 5,000 feet of strata, exposed along the new U. S. Highway 99 from near the center of Sec. 10, T. 5 N., R. 17 W., S.B.B.& M., northwest to the start of the solid shale about half a mile south of the triple fork in Osito Canyon.

The First Division is composed of alternating members of sandstone, silt, and shale, each member containing a rapidly alternating mixture of these textures but with one or another of them predominating. Upward, the sandstones become more prominent, the shales between these purer, and both better bedded; a combination which suggests a progress toward purely lacustrine conditions. The lower 1,000 feet is largely medium-bedded brown silt, some bluish black, alternating with gray and buff sandstone. This part is not unlike the brackish Upper Miocene below, but has heavier and different bedding. In the next 1,500 feet sandstone increases, becomes heavier bedded, and the decreasing silts become less brown and more dark to bluish black. The upper 2,500 feet is composed of alternating members of heavy-bedded greenish gray sandstone and even-bedded dark silt and shale, with silt and shale predominating in the lower, and sandstone in the upper part of this member.

Up the northeast flank the First Division grades to sandstone and then pebbly sandstone (Fig. 6), becoming first lighter-colored and finally on the extreme northeast across the Clearwater fault (where some land-laid beds may be included) a very pale greenish white. It nowhere acquires the olive-tan strandward color of the purely lacustrine divisions above it, though it verges on this at its top. On the short southwest flank, toward the San Gabriel fault, it grades rapidly to reddish conglomerate.

The First Division is evidently not a purely lacustrine deposit, but a nonmarine deposit laid down in a far inland bay deviously connected with, and feeling the pulse of, the distant sea. The bedding of

FIG. 7.—Axial view looking north by northwest across French Flat at continuation (offset) of section shown in Fig. 6. San Gabriel fault passes through dark notch in skyline on left. Granite on its left. Dark peak on right of notch, and sunlit escarpment in gorge directly below, expose reddish conglomerate of Second Division along fault. Notice gradation from conglomerate to shale down dark ridges, almost solid shale of synclinal center (two sandstones more than 3,000 feet apart), and on far right that this shale has started to grade back to pebbly sandstone of northeast flank (for which see Fig. 6). Synclinal axis: light-colored foreground with two ridge-forming sandstones is dull shale in lower part of Second Division. Above this is multi-colored shale in upper part of this division, then shale and sandstone of Third Division, and distant badlands of Fourth Division. Far beyond dark peak on left, crystalline slab of Frazier Mountain can be seen lying slid across sunken point of basin. Dim, bare mountains of middle skyline are across San Andreas rift.

its probably somewhat brackish lower part suggests the influence of tides, and the upper part was perhaps not wholly free from this influence. During the early work thirteen years ago the writer collected a series of shale samples along the old Ridge Route which were submitted to G. H. Doane and P. P. Goudkoff. The report was verbal, and the material is no longer available. He remembers that fresh-water ostracods were reported from above the First Division, and, if he recollects correctly, from its upper part.

Second Division (*Middle Pliocene*?).—This comprises approximately 7,000 feet of sediments exposed along the new U. S. Highway 99 from the beginning of the solid shale near the triple fork in Osito Canyon northwest about to the mouth of Liebre Gulch, where a pumping station is now located.

The Second Division (Fig. 7) is here essentially solid shale interrupted by two prominent, hard, heavy-bedded sandstones, one approximately 50 feet thick which crosses the head of French Flat about 1,500 feet above the base, and the other, some 150 feet thick, which initiates the gorge or narrows about 5,000 feet above the base of the division. These are the sandstones whose abrupt appearance and disappearance in an otherwise solid shale has previously been referred to as presenting a problem regarding the mechanics which produced them.

The lower and thicker part of the Second Division is shale weathering dull greenish to faint maroon, with thin and very persistent bedding (Fig. 8, above). The upper and thinner part is rusty-weathering, multi-colored to orange-brown, hard, more or less calcareous shale, also with thin and very persistent bedding (Fig. 9, above). From a distance this axial exposure of the Second Division has the coloring of Sespe (non-marine Oligocene), and the bedding of Monterey (marine Upper Miocene) deposits. On close inspection it resembles neither, but is peculiar to itself. The age of calcareous samples from the upper part, with their bright banding, straight, vertically diffused bedding, and extreme hardness, is never guessed by geologists who have not seen the section, due to the prevailing softness of California marine sediments and the scarcity of purely lacustrine deposits in coastal parts of the state. The most common guess is Paleozoic.

Up the northeast flank the shale section grades in a short distance to olive-gray and olive-tan pebbly sandstone with a few stringers of silt (Figs. 8 and 9, below), with possibly some land-laid beds on the extreme east. On the narrow southwest flank, toward the San Gabriel fault, it grades in an even shorter distance to reddish conglomerate (Fig. 7).

FIG. 8.—*Above:* Thin-bedded dull greenish to faint maroon shale in lower part of Second Division. New highway, near synclinal center. *Below:* Heavy-bedded, olive-gray pebbly sandstone in lower part of Second Division. Old Ridge Route, about one-third up northeastern flank. Compare this photograph with one above to see gradation that has taken place in $1\frac{3}{4}$ miles toward northeastern strand.

The Second Division has all the earmarks of a purely lacustrine deposit. There appears to be no trace of tidal influences. The thin, persistent bedding, diffused vertically, of the shales, and their gradation to conglomerate in almost incredibly short distances, are unlike anything in the marine or brackish column of California, although there is some superficial resemblance in their bedding to Upper Miocene marine shales, providing a clue to the very quiet and fairly deep marine waters in which the latter must seemingly have been laid down. The lake may have been deep along the synclinal axis, but was not necessarily so. Depths below its weak wave action appear to have been sufficient.

That the lake had an outlet, either steady or intermittent, seems fairly certain for reasons previously given. The straightness of textural bands across the course of Piru Creek where this creek now crosses the San Gabriel fault, and the present absence of any antecedent stream to Ventura Basin, indicate, with the direction of tilting, that this outlet was far to the northwest.

Third Division (*Upper Pliocene* ?).—This comprises about 6,000 feet of strata exposed along the new U. S. Highway 99 from the mouth of Liebre Gulch northwest to the junction of Peace Valley with the Cañada de los Alamos (Fig. 10).

In the Third Division sandstone alternates with shale as in the First Division, but the sandstone is much less prominent and there is no suggestion of anything but purely lacustrine conditions. The shales, which dominate, are as a rule softer and less pure than in the preceding division, and are of more numerous varieties. There is some rusty-weathering multicolored shale in basal parts, for the various divisions all grade texturally one into the other. Perhaps the commonest variety is grayish or grayish brown and somewhat silty, but insufficient observations were made in the synclinal center to rate the various colors. In the upper part considerable light-colored orange-brown shale occurs which is locally concretionary (Fig. 11, above). The sandstones, not very prominent in the synclinal center, are prevailingly gray or greenish gray.

Up the northeast flank, which veers toward the east due to the clockwise trend of tilting, the entire Third Division grades in a short distance to olive-tan pebbly sandstone (Fig. 11, below) similar to that in the underlying division but more poorly indurated. Uneroded parts on this flank extend farther strandward than do the previous divisions. Conglomeratic parts near the strand contain few boulders, and tend to be light-colored. Southwest of the synclinal center, toward the ancient scarp of the San Gabriel fault, the Third Division like those

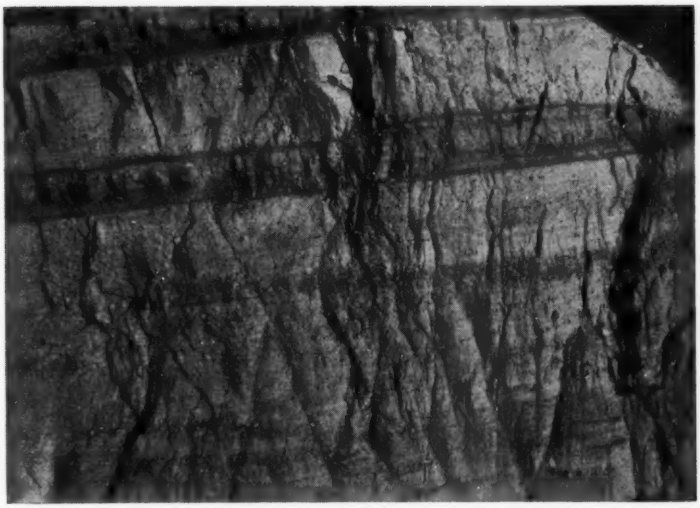

FIG. 9.—*Above:* Thin-bedded, rusty, multi-colored hard calcareous shale in upper part of Second Division. New highway, near synclinal center. Figure standing near lower margin gives scale. *Below:* Medium to heavy-bedded, olive-tan pebbly sandstone in upper part of Second Division. Old Ridge Route, about two-fifths up northeastern flank. Compare with view above to see gradation that has taken place in 2½ miles toward northeastern strand.

preceding it grades in remarkably short distances to reddish conglomerate (Fig. 10).

It seems evident from the coarser average texture combined with a somewhat less pronounced areal gradation of sediments that the lake was beginning to shallow; that slippage along the San Gabriel fault, after increasing to a maximum in the preceding division, was now starting to slow down.

PLEISTOCENE(?)

Fourth Division (*Lower Pleistocene*?).—The Fourth Division is exposed from the junction of Peace Valley and the Cañada de los Alamos northwest to Frazier Mountain, and presumably continues under the latter to the point of the structural triangle. The exposed thickness is slight northward along the new highway from this junction to a secondary syncline which crosses Peace Valley 1½ miles above its mouth, due to edge deposition. Westward in the Cañada de los Alamos somewhat less than 3,000 feet is exposed. North of the secondary syncline mentioned the structure in Peace Valley rises for 2 miles to a probably faulted east-west line and reveals about 4,000 feet of beds, the basal part of which may or may not represent a reappearance of coarse upper strata of the Third Division.

The Fourth Division (Fig. 10, distant white) is somewhat uniformly white, medium to heavy-bedded, soft arkosic sandstone, much of it pebbly, with silty gray sand partings. No true shale has been observed in it anywhere, but there are occasional minor lenses of silt. It grades up from the underlying division in a way which, though the two divisions are on the whole very different, causes the contact between them to be a transition zone to regionally coarse deposition similar to that existing between the marine Pliocene and marine Lower Pleistocene in the near-by Ventura Basin. On the coarse eastern flank of Ridge Basin nearly all differences between the various divisions disappear. In the synclinal center, however, the Fourth Division forms a unit with a characteristic aspect (Fig. 12) markedly different from anything that precedes it.

In contrast with all underlying divisions the Fourth has a relatively uniform texture and thickness eastward, although there is some coarsening to gravel toward the strands. Since a thousand or so feet of upper strata have doubtless been eroded from the synclinal centers the 3,000 feet assigned is less than the original maximum. The division is exposed over a larger area than is any other, but undulates so in anticlines and synclines that its total exposed section is not great.

FIG. 10.—Diagonal view looking northwest by west from Reservoir Hill across Liebre Gulch at continuation of section shown in Figs. 7 and 6. Prominent hills in foreground, from margin to margin, expose Third Division, which can be seen to grade from heavy-bedded conglomerate in Beartrap Canyon on far left to thin-bedded shale along Piru Creek and then back to gray pebbly sandstone up long ridge on right. In distance (white) is coarse Fourth Division, showing much less gradation. On skyline, right of center, again looms crystalline slab of Frazier Mountain, slid toward left from across San Andreas rift to rest on sunken point of Ridge Basin above Fourth Division. High, dim mountains on left of this division are granitic and across San Gabriel fault. Immediately above dark pole in right foreground can be seen steeply dipping beds along dying Clearwater fault.

The aspect is that of the last stages of a broad, shallowing lake having a large intake and outflow, in which the universally slight depth of water causes storm waves to spread traction-laid sediment somewhat evenly over the entire bottom, and keep the finest material in such a state of agitation that it can not permanently settle. Temporary settlings from suspension are stirred up again and again, until this fine material is eventually lost through the large outflow. Transverse uniformity would tend to be aided by the then far clockwise direction of tilting, which was toward the point of the triangle and the supposed location of the outlet rather than toward the San Gabriel fault.

Tentative assignment of the Fourth Division to the Lower Pleistocene is at present necessarily based on circumstantial evidence; chiefly regional controls difficult to describe in a few words. The Pleistocene was inaugurated in California by the marked inception of the Coast Range revolution. The first movement did not immediately remove the waters from the state, but deluged them with so much material that only the coarser particles were retained near shore, resulting, in all California basins, in almost universally coarse deposition. The time of change is dated in California by an abrupt change from uppermost Pliocene marine invertebrate faunas of fairly high extinction to Lower Pleistocene faunas whose extinction is but a few per cent. In the adjacent Ventura Basin 4,350 feet of coarse, white, marine and brackish Lower Pleistocene with an average extinction of 4 or 5 per cent conformably overlies 15,450 feet of marine Pliocene the extinction in whose uppermost part is 15 or 20 per cent. Since in eastern Ventura Basin the strandward Upper Pliocene, and to some extent the Middle and Lower Pliocene is also coarse, white, and soft, it is necessary to emphasize that it is to an abrupt regional transition that significance is attached, and not to physical aspects which are locally present throughout the column.

Considering that the marine Ventura Basin and the nonmarine Ridge Basin were opposite types of aqueous deposition which necessitates specific differences, there is a remarkable similarity of the 21,000-foot post-Miocene succession in the latter to the 20,000-foot succession of this age in the former as regards general and major aspects. This implies that the land and diastrophic factors affecting both were under a similar basic control, a feature which will be better understood if it is realized that in regions as far apart as southern and middle California the marked general change in regional control at the inception of the Pleistocene can be recognized.[19]

[19] J. E. Eaton, "Divisions and Duration of the Pleistocene in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 2 (February, 1928).

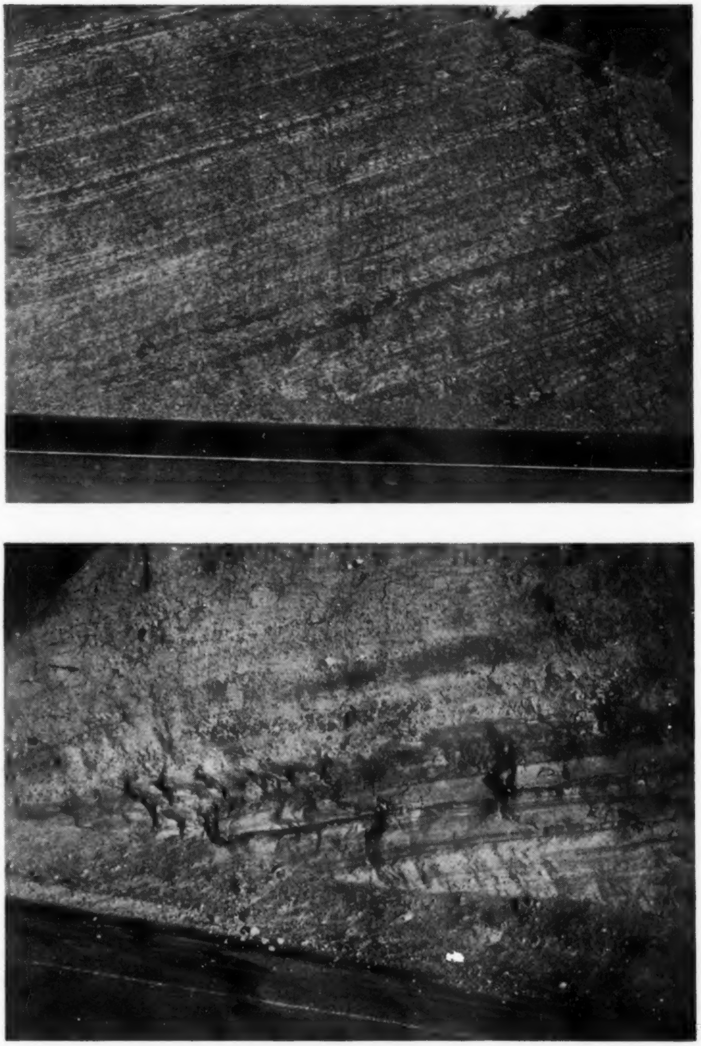

FIG. 11.—*Above:* Thin-bedded, orange-brown concretionary shale in upper part of Third Division. New highway, near synclinal center. *Below:* Medium to heavy-bedded, olive-tan conglomerate and sandstone in upper part of Third Division. Old Ridge Route, about two-thirds up northeastern flank. Compare with view above to see gradation that has taken place in 4 miles toward northeastern strand.

Geologists familiar with the regional change in control can not fail to note the rapid transition in Ridge Basin at the junction of Peace Valley with the Cañada de los Alamos to universally coarse, soft white sandstone revealing the inception of a flood of increased material. The white wall (Fig. 10) which greets them there after travelling north through 18,000 feet of nonmarine Pliocene (?) brings a picture of the white wall that looms before them in middle Ventura Basin after travelling south through 15,450 feet of marine Pliocene in Adams Canyon. This regional change in both basins is not to be confused with local strandward phenomena which occur throughout the column.

An unidentified horse tooth is reported to have been found by unknown persons in or near the Fourth Division. The extreme eastern flank of the First and Second divisions, only locally examined by the writer as shown by the question-marked contacts on this flank in Figure 2, may, as mentioned, include some bordering land-laid beds in or near Cienaga Canyon. The fresh-water ostracods and mollusks of the basin are practically unexamined.

CONTACTS

The nature of the contact between the Upper Miocene and the Pliocene(?) series in Ridge Basin has not been determined by the writer. Contacts between successive divisions of the post-Miocene succession all appear gradational to him, and pending further evidence he treats the succession as being conformable throughout along the synclinal axis. Fringe unconformities may, and should, exist near the far eastern strand due to minor fluctuations in the boundary of Ridge Lake. In this connection, however, marked thinning and gradation of the three lower divisions toward the northeast strand, and disturbances along the Clearwater fault, give deceptive appearances of unconformity.

Clements[20] reports a slight discordance at a horizon which from a triple-dotted line on his map would start on the west in the Third Division and strike eastward across the Second Division of the present paper. He informs[21] the writer that this line was meant to be approximate only. The reported discordance he states to have been observed on the far east. Clements called the beds above the line referred to the Ridge Route formation. The top of this formation was beyond the area he discussed and was not defined. From a reference by him to faunas on the north the term may represent a grouping of the Third and Fourth divisions along the synclinal axis, but, as mentioned, a

[20] *Op. cit.*, p. 218 and Fig. 1.

[21] Letter dated December 27, 1938.

lower division seems to be involved on the east. Clements mapped the First and Second divisions of the current paper as Modelo (Miocene), and beds northeast of the Clearwater fault herein tentatively included in the First Division as Sespe? (Oligocene).

PRESENT STRUCTURE

Some of the deformation now visible in Ridge Basin occurred during deposition. The northwest plunge of the syncline appears to

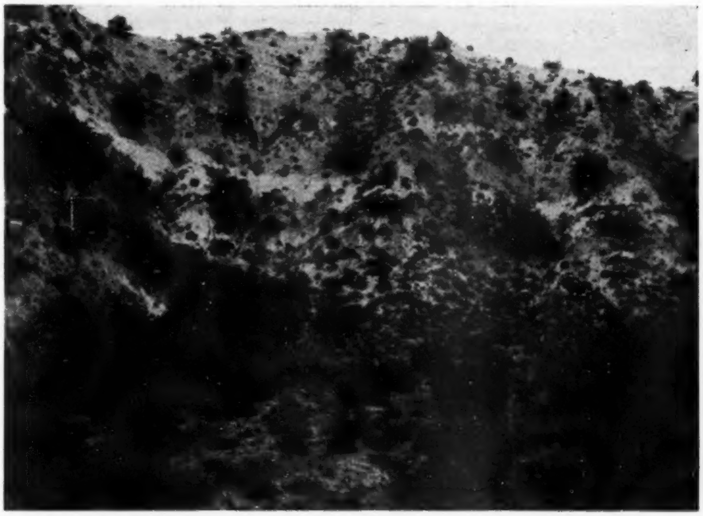

FIG. 12.—Heavy-bedded, arkosic, white, pebbly sand with interbedded gray silty sand of Fourth Division. North side of Cañada de los Alamos, ½ mile west of mouth of Peace Valley.

have had in large part such an early origin, the older divisions being tilted while younger ones were being laid down. This tilting was presumably a phenomenon of the supposed tension or differential pressures causing and attending deposition. Folding of the syncline transverse to its axis, on the other hand, is indicative of compression, and obviously occurred at a later date, during the Coast Range revolution which highly compressed, deformed, and overthrust coastal California. High dips in the Third Division comparable with those of preceding divisions show that this transverse folding was Pleistocene in age, and such dips in the Fourth Division that it was chiefly Middle and Upper Pleistocene.

The San Gabriel fault, so active during deposition, is believed to have now been frozen and essentially dead for a million or more years in southeastern Ridge Basin, though undoubted thrusting has lately taken place and is presumably still active along it farther southeast at and near the type locality for the fault. The chief evidence for recent vertical inactivity of the fault in southeastern Ridge Basin is the feature that throughout the Violin Canyon and Beartrap Canyon quadrangles, which cover much of its local course, the conglomerate northeast of the fault and the granite southwest of it stand at practically the same height. The implication is obvious. This equal level on both sides of the fault represents an old erosion surface, now deeply dissected, whose vertical relations across the fault have not been perceptibly disturbed while the present deep canyons in it were being eroded.

This feature, which seems good evidence for late vertical stability, does not, however, disprove possible late horizontal slippage. The San Gabriel fault now seems to be offset toward the southwest at several places northwest of Beartrap Canyon by cross faulting. The direction of the apparent offsetting is in accord with pressure directed southwest from the increasing bend in the San Andreas rift. If horizontal slippage were recently active along the San Gabriel fault the obstruction to this furnished by the offsets might be expected to cause profound local deformation where the angular offsets occur. Such has not been observed by the writer in a rapid reconnaissance, but might be uncovered, if present, by closer examination. Strike canyons which exist along the San Gabriel fault may be due either to the brecciated nature of the fault zone or to horizontal movement. The circumstance that the divides trending across the fault trace are not noticably offset does not favor recent appreciable horizontal slippage. Evidence against late vertical movement along the San Gabriel fault between Castaic and Beartrap Canyon appears to the writer to be strong. Whether slight, recent horizontal slippage has occurred along this fault is undetermined.

Liebre fault.—The Liebre fault zone along and near the southwest base of the mountain of the same name does not seem to have affected deposition, and is therefore assumed to have been Pleistocene in origin. The mountainward fault may not be continuous. Sediments locally cross it, and the throw is probably small. The basinward fault is larger and is seemingly continuous, with a relatively straight trace and a throw inferred to be chiefly horizontal.

Clearwater fault.—The Clearwater fault is of the rift type. Clements[22] recognized that it horizontally offsets as far as 2 miles strata

[22] *Op. cit.*, pp. 222–24.

older than those herein described as the Third Division. The present writer maps the Clearwater fault as horizontally offsetting the Eocene series about 2 miles, with the surface of each younger succession to the northwest offset a progressively less distance, the *surface* magnitude of the fault dying out basinward. The impression gained is that the stratigraphic succession, though horizontally offset, is essentially the same on both sides of the fault, and that most of the movement therefore occurred in the Pleistocene. The Clearwater fault, due to its magnitude, is viewed as probably continuing across Ridge Basin in the basement rocks, the deeper movement being changed upward into surface folding basinward much as the central shear zone in Los Angeles Basin changes deep-seated slippage into folding in a thick, plastic blanket above.

Diastrophic history subsequent to deposition.—At the inception of the Quaternary revolution, which had been slowly prepared for throughout the Pliocene, the regional control previously mentioned became simultaneously operative in all parts of coastal California. Increasing diastrophism deluged the basins with material, and, since their cubic capacity (area and subsidence in time) was sufficient to retain only the coarser fraction of this, a change to regionally coarse sedimentation took place in these basins. After several thousand feet of Lower Pleistocene deposition, dated by a rapid change to marine invertebrate faunas with an average extinction of but a few per cent, the second phase of the revolution began and the waters receded into ocean deeps, leaving California and its continental shelf high and dry, as is shown by the feature that synclines on and near the shelf were subsequently degraded thousands of feet.

Middle Pleistocene time in the state was a long interval of erosion during which profound degradation of coastal areas took place, and V-canyons of the Sierra Nevada range were deepened in granite several thousand feet. This interval Le Conte[23] named Sierran time. As it was a time of continental emergence which only in great deeps such as coastal California yields Pleistocene marine faunas below it, the interval has ofttimes been referred to the Upper Pliocene outside of this state. However, its diastrophic relations and many thousand feet of marine sediments lying below and containing faunas but a few per cent extinct show it to be not only Pleistocene (according to Lyell's definition of the epoch) but Middle Pleistocene in age.

Subsequent to the greater part of the Pleistocene degradation in California, if the Sierra Nevada record of canyon cutting followed by glaciation is representative, three or four glacial stages occurred in

[23] Joseph Le Conte, "The Ozarkian (Sierran) and Its Significance in Theoretical Geology," *Jour. Geol.*, Vol. VII (1899).

mountainous regions. The last of these was terminated by a transgression of the sea which not only reoccupied the deeply eroded and stream-cut continental shelf, but flooded many of the present valleys to depths as great as 1,500 feet, as is revealed by a series of marine terraces cut to this height. Regression has lately taken place to the present coast line, and, perhaps, another glaciation in the dying, pulsative series may eventually appear.

The Quaternary revolution increased the rate of horizontal slippage along the San Andreas and Garlock rift faults. Available data show that the Pleistocene slippage along both rifts more than exceeds that during all previous epochs combined. This indicates that the great bend in the San Andreas rift occasioned by movement of the southern Sierra Nevada westward along the line of the Garlock rift was perhaps doubled in angle during the Pleistocene, thus quadrupling the resistance to horizontal movement along the San Andreas. The increasing pressure southwestward resulted in extreme shortening and overthrusting in the region between the bending rift and the coast.

It is to be noted that Ridge Basin, though now for long locked and static, still enjoys a measure of the protection from compression that it has had since the Middle Miocene; it still occupies a little eddy in the maelstrom of compression. When every other basin in the state with a comparable thickness of plastic sediments in relation to its width has been crushed and has had its strata locally overthrust and overturned, Ridge Basin, the most susceptible of all, is transversely the least deformed deep basin in coastal California. Lying in the very shadow of the cause, except for the steep tilt during deposition, and some oversteepening along the San Gabriel fault and the San Andreas rift, its 23,000 feet of incompetent sediments are relatively little disturbed. This would seem to corroborate its origin as a potential void arising from differential pressures on the north and south; differential pressures which the visible phenomenon mentioned indicates still to exist in part.

Frazier Mountain thrust slab.—A local feature connected with the great thrust arcs which ride south and southwest for 50 miles from the bending San Andreas rift was the sliding in Middle or Upper Pleistocene time of a crystalline slab across the point of Ridge Basin, to rest in part on the basin and in part beyond it (Fig. 1). This was originally described, and its basic cause recognized, by Buwalda, Gazin, and Sutherland[24] as follows.

The contact between the crystalline rocks above and the sedimentary

[24] *Op. cit.*

formation below practically parallels the contours, but rises gradually from the 5,000-foot contour at the eastern end of the mountain to the 6,000-foot contour at the western end . . . Frazier Mountain is a slab of crystalline rocks about eight miles in east-west length, over four miles in width, and about one-half mile in thickness. Like certain peaks in the Alps, it is a mountain without roots. A minimum measure of the distance through which the mass has ridden forward is its width of something over four miles . . . It is presumably not a coincidence that it lies in the concavity of one of the most acute curves of the San Andreas fault.

The slab, by elimination, would seem to have come from across the San Andreas rift, and from the northeast. There are several reasons for this, only the more obvious of which need be mentioned; namely, on the southeast lies Ridge Basin and its sediments, on the south is an ancient antecedent canyon 2,000 feet deep whose bottom is that distance below the western base of the slab, on the southwest and west are sediments, and on the northwest and north are mountains of comparable height with no voids even remotely approaching the mass of Frazier Mountain. The remaining area on the northeast in the vicinity of Castaic Lake has the requisite void (probably larger before late thrust convergence), with, exclusive of the Garlock rift zone, a depth tolerance for subsequent brecciation and erosion.

As may be seen from Figure 1, the area between the Garlock and the San Andreas rifts is a triangle which is moving relatively east while adjacent regions north and south of it are moving relatively west. The resulting tendency would be for any mass, particularly a high mass, situated on or partly on the point of the triangle to be dragged off of it in a westerly direction by one or both of the adjacent regions moving in this direction. If dragged by the Garlock rift the mass should have been rotated counter-clockwise; if by the San Andreas rift, clockwise. The indicated counter-clockwise rotation of Frazier Mountain suggests that its mass was originally moved by the Garlock rift. The depressed point and outlet of Ridge Basin below to the south would provide a trap in that direction; a greased slide. The more effective mechanics may have been a thrusting of the mass toward the San Andreas rift, and then a gravity slide across the rift to a sink occupying the then low point and outlet of Ridge Basin. In this connection the slab was presumably placed south from the junction of the two rifts, and now lies west of this junction as a result of subsequent horizontal movement along the San Andreas.

DRAINAGE SUBSEQUENT TO DEPOSITION

In past years various geologists have remarked to the writer that the course of the large headwater system of Piru Creek, which drains

northeast, then southeast, then west, and finally south, seems an anomalous one. The Sespe drainage system, which involves a long eastward course structurally determined by a syncline and then an abrupt turn southward generally comes in for comment, but is recognized as being a much simpler problem than the Piru system which crosses, parallels, and then recrosses the San Gabriel fault. Sediments of the Second Division in Ridge Basin deposited in apparently straight, uniform bands across what is now the gorge of Piru Creek seem to show that the creek did not reach Ridge Basin during this deposition, but that it subsequently captured its headwaters. Figure 13 presents the writer's interpretation of the approximate way in which this phenomenon may have come about.

The Castaic Creek drainage system is obviously a subsequent one, which, branching from the antecedent Elizabeth Canyon perhaps about Upper Pliocene time (Fig. 1), extended its headwaters north; first up the southward tilting flank of the divide, and, once established, eventually on to Liebre Mountain (Fig. 13). That Ridge Lake never had an outlet to this system is indicated by the strike of Liebre Gulch and West Fork, by the now high intervening divide, and by the feature that such a low outlet, once established, would not be likely to be pirated by Piru Creek.

During most or all of the existence of Ridge Lake the present headwaters of Piru Creek drained to this lake, which, for reasons given, seemingly drained, in turn, through some northern outlet. The general relation would appear to have continued during the Middle Pleistocene, except that Piru and Canton creeks had by then probably crossed the San Gabriel fault and established small drainage areas in a part of Ridge Basin, as is suggested by the deep, straight, converging courses of Liebre Gulch and West Fork toward the former (Fig. 13, *A*). Piru Creek might have eventually captured much of its present headwaters without outside aid, as the northward outlet for these along or near the San Andreas rift must have been intermittently obstructed by fault slippage. The sliding of the huge mass of Frazier Mountain across the northwestern outlet, effectually blocking northern egress, made any such slow progress unnecessary, and may have given the entire present headwaters of Piru Creek to it as one offering (Fig. 13, *B*).

The presence of ancient Lockwood Lake as a result of a damming action by the Frazier Mountain slab is suggested by the nearly uniform level of 5,600 feet elevation for the flatter valley edge on the west, north, and east; a uniformity under differing local conditions difficult to explain by other than standing water. The presence of

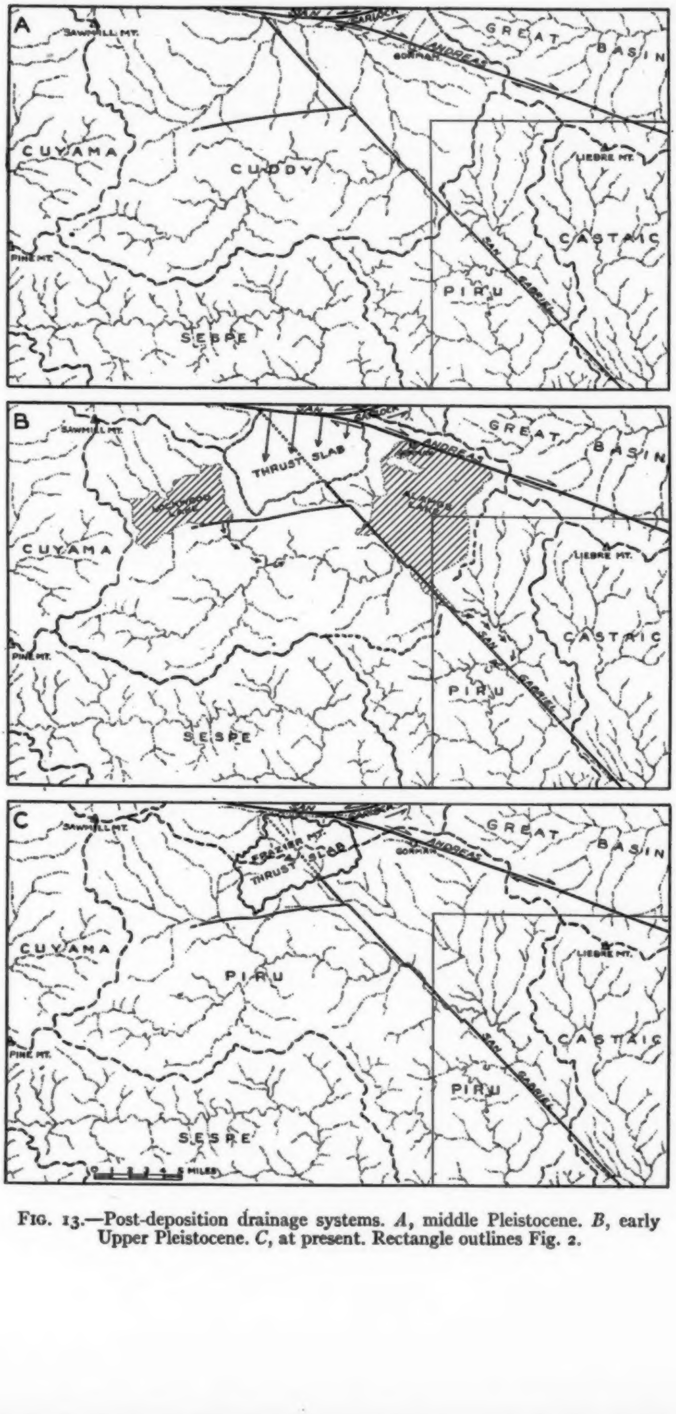

FIG. 13.—Post-deposition drainage systems. *A*, middle Pleistocene. *B*, early Upper Pleistocene. *C*, at present. Rectangle outlines Fig. 2.

Alamos Lake (not to be confused with the older Ridge Lake) is not so clear, due to subsequent differential tilting and erosion, but a level for this at between 3,500 and 4,000 feet present elevation, according to these differential factors, is indicated. The lowest divide was inferentially between the mouth of Buck Creek and Beartrap Canyon, and the lake may have overflowed there into Piru Creek. It presumably barely escaped becoming tributary to the Great Basin. As soon as Alamos Lake began to pour over a divide toward Piru Creek the latter had acquired its present headwaters. It is to be noted that much of the flatter territory now drains not south to the main channel but southeast through the Cañada de los Alamos to Peace Valley. It is believed that this subsequently came about as a result of known cross faulting that may have interfered with an earlier outlet southward toward the mouth of Snowy Creek. Family piracy between the poorly adjusted flatter tributaries is indicated; indeed, capture of the upper Cañada de los Alamos drainage by another branch of the main channel of Piru Creek now seems imminent.

Piru Creek, which to all appearances did not extend to Ridge Basin until after Ridge Lake disappeared, did subsequently capture its headwaters. It is possible that this creek cut through to Ridge Basin soon after deposition ceased and captured most of its upper drainage system before the Frazier Mountain episode; that the blocking by this slab of a northern outlet merely rearranged certain headwaters and added others. However, it is believed that the thrust slab is more likely to have been the decisive influence. Due to the enormous Pleistocene degradation, ranging up to 16,000 feet along Piru Creek, the steps in the capture can only be approximated. Those inferred in Figure 13 doubtless depart somewhat from the actual conditions, but it is felt that they are sufficiently near these for purposes of illustration.

BEARING OF RIDGE BASIN ON AGE OF SAN ANDREAS RIFT

The age of the San Andreas rift as a continuous fault line is difficult to ascertain due to the large horizontal throw with its intense shattering, and to a deep, differential erosion of the slivers. That the rift is at least as old as early Pliocene has been inferred for some time from the feature that the inland Pliocene seas paralleled it but did not cross it widely, and from other data. It has been surmised from certain relations that the rift existed in the Upper Miocene. However, as the Upper Miocene seas crossed it widely, and as most of the observed horizontal slippage along the rift occurred subsequent to that epoch, there has been some doubt regarding this earlier age.

Existence of the San Gabriel fault as an offshoot of the San Andreas, indicating that the bend in the rift with its attendant compression of coastal areas had started, however slightly, by Upper Miocene time, furnishes more evidence of antiquity than was previously available. Since this bend is seemingly caused by a westward movement of the southern Sierra Nevada along the line of the Garlock rift, a similar antiquity for the latter rift is suggested. To judge from the thinness of the Upper Miocene conglomerate along the San Gabriel scarp, the localized tension, and, inferentially, movement and bend along the San Andreas rift were all relatively small in the Upper Miocene, but they are deemed sufficient to indicate that a connected line of rifting then existed.

The basin also illustrates the magnitude of the San Andreas rift. As has previously been mentioned, in its more central, ruthless part the San Andreas recognizes only the Garlock rift, to which it pays deference by changing its course at their junction and bending in a wide arc. The San Gabriel with its 23,000 feet of vertical throw would not be called a puny fault, yet the San Andreas is seemingly unaffected by it. The throw of the San Gabriel scissors from side to side in its ninety miles of length. Changing near Castaic, it begins a sustained rise northwest. The San Gabriel enters the San Andreas with a vertical throw in excess of four miles, and is lost. The great rift gives no sign. A geologist travelling northwest along it unaware of the meeting place would probably not notice the junction, but if he glanced to the left at Tejon Pass he would see a line of dark and somber mountains that strike toward the rift and disappear.

SUGGESTED ITINERARY

A trunk highway, U.S. 99, follows the plunging axial syncline of Ridge Basin. The many geologists who travel this highway an average of several times a year see the 23,000-foot section, continuously and well exposed along this axis, more often than any other section in California. The highway traverses the finer-grained facies, but at various points there are vistas where the gradation of shale to reddish conglomerate paralleling the San Gabriel fault as a straight, narrow band can be observed. The northeastward gradation of fine-grained facies to pebbly sandstone can not be adequately perceived from the new highway. For those travellers who on some trip have two or three hours to spare, and may be interested in more panoramic views of the basin, the following itinerary is suggested.

1. Take the forestry road to Whitaker Peak, which branches west from the U.S. Highway 99 about 3 miles south of French Flat and 1 mile south of the turnoff to the Los Angeles city playground. The road winds steeply upward through strata of the First Division. Notice the gradation to coarser sediments on the climb; to sandstone, then to pebbly material near the top, and finally to conglomerate at the crest of the ridge. Continue through angu-

lar conglomerate beyond the crest down the gentle grade of the main road for about one-third of a mile to a good exposure of the San Gabriel fault in the road wall. Return to the ridge crest and turn left on a narrow side road, dangerous after rains, which travels northwest along the ridge to a view of Piru Gorge cut in granite on the northwest, the Second Division on the north, and the First Division on the east. Note the gradation of the Second Division from reddish conglomerate along the fault trace to shale in the synclinal center and then back to sandstone on the northeast flank.

2. Return to U.S. Highway 99 and follow this road north about 6 miles to the mouth of Liebre Gulch, which may be identified by a pumping station with several large oil tanks. Take the dirt road through this station that winds easterly up a ridge to Reservoir Hill and the old Ridge Route, noticing the gradation from shale to sandstone, and finally to pebbly sandstone. From the balcony of the forestry lookout station on top of Reservoir Hill a panoramic view of Ridge Basin surrounds the visitor. Easterly, from south to north, lies the light-colored, detrital flank of the First, Second, and Third divisions. Observe that the total thickness there is only a small fraction of that along the synclinal axis. Also, north of east, the overlap of successively younger strata on granite. A little south of east is Redrock Mountain (Granite). Downthrown south of a minor east-west fault at its foot is the gray base of the First Division, offset two miles along the Clearwater fault which bounds it farther south. The dying trace of this fault can be followed by the eye northwesterly from the Eocene as a line of disturbed and rotated strata in the lacustrine succession. Looking southwest, in the central syncline are shales of the Second Division, and beyond these the high, dark, conglomeratic ridge along the San Gabriel fault. Northwest, across Liebre Gulch in the foreground, is the Third Division, grading from conglomerate on the far left to shaly beds at the synclinal center and back to sandstone on the right. Beyond the Third Division the Fourth Division can be seen as a snow-white band in the distance, extending from side to side of the basin. On the central skyline is crystalline Frazier Mountain. It has been slid across the narrow point of the basin, after travelling from a site computed to be about 7 miles to the right.

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VERDEN SANDSTONE OF OKLAHOMA—AN EXPOSED SHOESTRING SAND OF PERMIAN AGE[1]

N. WOOD BASS[2]
Tulsa, Oklahoma

ABSTRACT

The Verden sandstone is a remarkable narrow elongated body of sandstone which crops out in a long line of flat-topped buttes extending northwestward a distance of 75 miles from Stephens County, through southwestern Grady and northeastern Caddo counties, into Canadian County, Oklahoma. It has long been of interest to petroleum geologists because of the similarity of many of its features to those of the shoestring oil-producing sands of northeastern Oklahoma and southeastern Kansas. The Verden sandstone body is only 10 feet thick and less than 1,000 feet wide at most places. It lies in the redbeds portion of the Permian series. The sandstone occupies everywhere the same stratigraphic position within a range of a few feet, in the redbeds, and lies within a sequence of regularly bedded thinly laminated silty sandstone, silt, and gypsum of the Marlow formation. It is characterized by relatively thick beds of medium- to coarse-grained sandstone which are steeply cross-bedded with northwest dips, and are interbedded with thin beds of fine-grained horizontally laminated sandy shale. The sand grains have a wide range in size but are sorted into layers in which grains of a single size predominate. The fine-grained beds contain wave ripple marks and giant ripple marks that trend nearly parallel with the sandstone belt. The sandstone is a firm hard rock composed of well rounded quartz and subangular chert grains and of calcium carbonate which makes up 50 per cent of the rock. Marine fossils are common.

That the Verden sandstone was deposited as some form of a barrier beach, probably as one or more spits that extended across the mouth of a broad shallow bay, near the shore of a shallow marine sea, is indicated by the evidence collected during this investigation. Apparently the coarse-grained cross-bedded sandstone was deposited by longshore currents that flowed northwestward and the fine-grained beds were deposited during quiescent periods when gentle waves and tides spread fine mud over the nearshore bottom. The coarse material in the sandstone was probably derived from beds of conglomerate in the underlying Duncan sandstone which were exposed near the southeast end of the sandstone belt and probably in other localities in the region. Most of the calcium carbonate in the bed was probably deposited originally as granular material composed of shell fragments, and was later dissolved and redeposited; a part may have been precipitated directly out of solution in the sea water and a part may have been precipitated out of water that passed from the lagoons and estuaries seaward through the sand bar soon after it was formed.

DISTRIBUTION AND FORM OF VERDEN SANDSTONE

The Verden sandstone is a remarkable, narrow, elongated body of sandstone in southwestern Oklahoma. Its outcrops form a long line of flat-topped buttes extending northwestward 75 miles from Stephens County through southwestern Grady and northeastern Caddo counties into Canadian County, Oklahoma. A view of one of the buttes is shown in Figure 1. The distribution of the sandstone is shown in Figure 2. About 30 miles of the northern half and about 10 miles of the southernmost part of the belt contain few outcrops of the sandstone because it is there largely concealed beneath younger deposits. Elsewhere most of the short gaps between outcrops appear to repre-

[1] Published by permission of the director of the Geological Survey.

[2] Geological Survey, United States Department of the Interior.

sent areas from which the sandstone has been eroded, but some gaps may represent local areas where the bed was not deposited. The positions of the many small outcrops widely distributed in T. 9 N., R. 9 W., were furnished by Russom[3] and, except the outcrop in Section 5, were not examined by the writer. Exposures of the sandstone are most abundant in the strip of country extending northwestward from Sec. 19, T. 6 N., R. 7 W., about a mile southeast of Norge, to Sec. 13, T. 7 N., R. 9 W., about a mile southwest of Verden.

FIG. 1.—Typical butte capped by Verden sandstone.

The width of the Verden sandstone in most exposures is only 200 to 600 feet but is as much as 1,500 feet locally. The thickness of the sandstone ranges from a few inches near its margin (Fig. 3) to 15 feet or more near the middle. It is only 8 to 10 feet thick in most localities. Few data are available that show the shape of the sandstone body in cross section, but many exposures of small extent indicate that the top and base of the sandstone are about horizontal, and in a few localities the top of the sandstone slopes southwestward at an angle of 2° to 5°. Exposures are adequate to show that sandstone is absent from the Verden sandstone horizon on both sides of the Verden sandstone belt.

[3] V. W. Russom, personal communication.

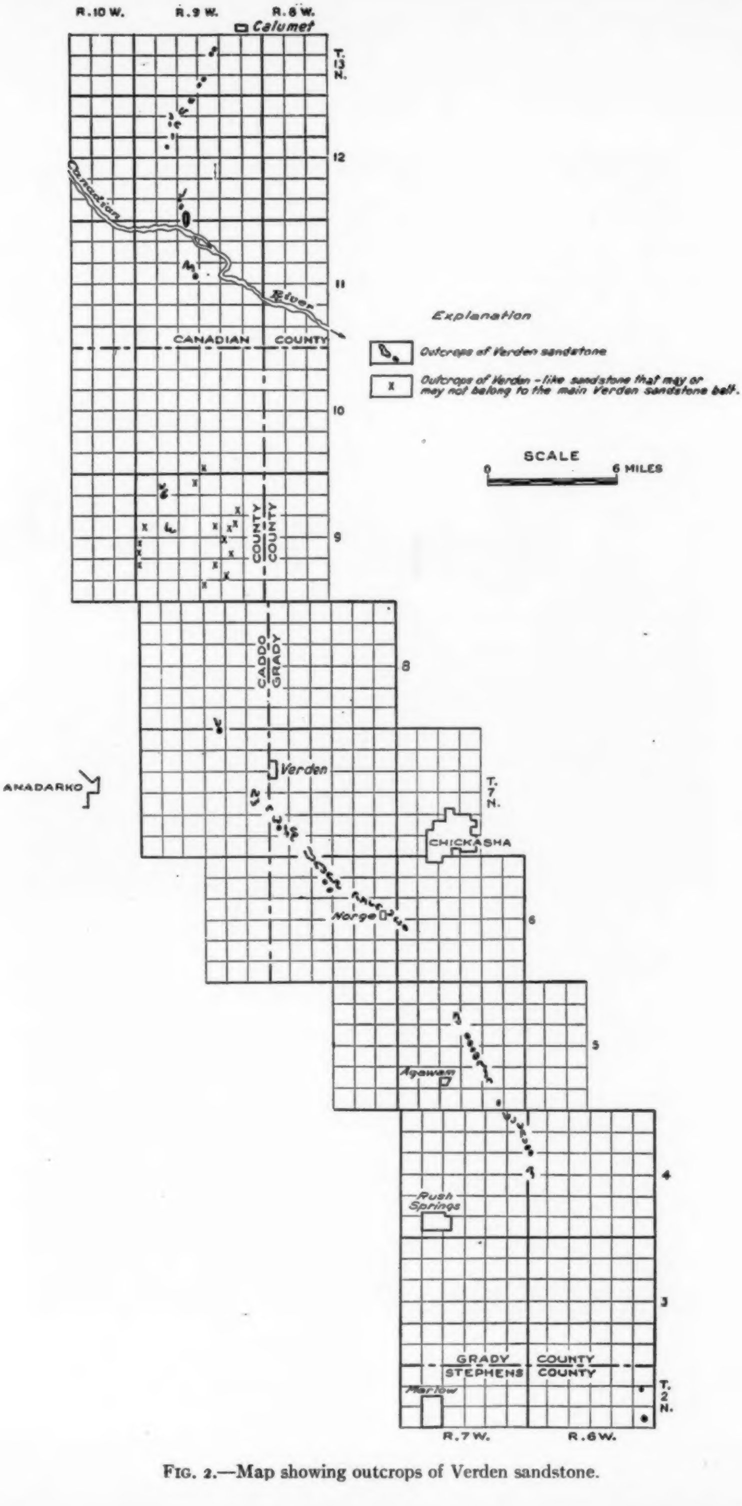

FIG. 2.—Map showing outcrops of Verden sandstone.

The Verden sandstone has long been of interest to petroleum geologists because of its similarity in many respects to the shoestring oil-bearing sands of northeastern Oklahoma and southeastern Kansas.[4] Like these sands the Verden sandstone is a narrow lens, or possibly a series of lenses that forms a narrow shoestring-like belt or trend[5] which is many times longer than wide. Like the oil-bearing shoestring sand trends, the course of the Verden sandstone belt deviates from a straight line only by broad sweeping curves.

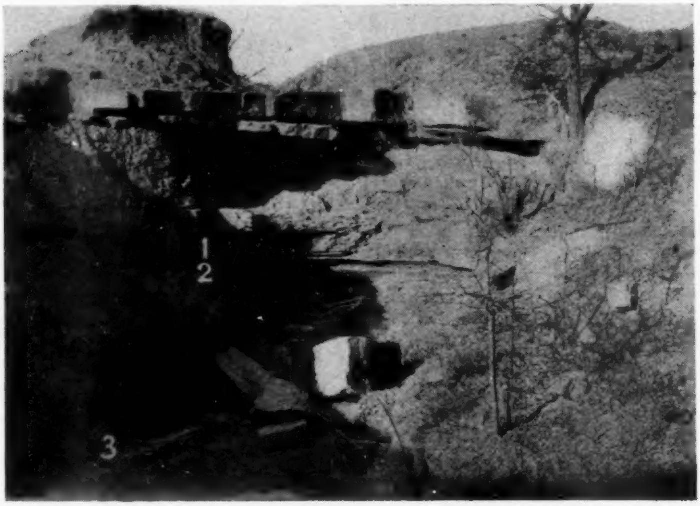

FIG. 3.—Thin beds in Verden sandstone near margin of sandstone belt, in the SE. ¼, SW. ¼, SW. ¼ of Sec. 19, T. 7 N., R. 8 W. Base of sandstone at 1; white gypsiferous clay beds at 2 and 3.

PRESENT AND EARLIER STUDIES

The Verden sandstone was described briefly several years ago by Reeves,[6] Sawyer,[7] Gould,[8] Stephenson,[9] and Becker.[10] It was described

[4] John L. Rich, "Shoestring Sands of Eastern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 2 (1923), pp. 103–13. *Ibid.*, Vol. 10, No. 6 (1926), pp. 568–80.
N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *ibid.*, Vol. 18, No. 10 (1934), pp. 1313–43.
N. W. Bass, Constance Leatherock, W. R. Dillard, and L. E. Kennedy, "Origin and Distribution of Bartlesville and Burbank Shoestring Oil Sands in Parts of Oklahoma and Kansas," *ibid.*, Vol. 21, No. 1 (1937), pp. 30–66.

[5] The belts of oil-bearing shoestring sand bodies in Kansas and Oklahoma locally are called "trends."

[6] Frank Reeves, "Geology of the Cement Oil Field, Caddo County, Oklahoma," *U. S. Geol. Survey Bull.* 726 (1921), p. 61.

FIG. 4.—Stone reef on coast of Brazil (after Branner).

at length by Meland[11] and was named the Verden channel sandstone by Reed and Meland.[12] It is shown as the Verden channel sandstone on the geologic map of Oklahoma by Miser.[13] The sandstone has been called the footprint sandstone[14] locally because it contains some carvings of human footprints and bird tracks (Fig. 5) on a small butte near the southwest corner of Sec. 7, T. 4 N., R. 6 W.

FIG. 5.—Carvings of human footprints and bird tracks in Verden sandstone near southwest corner of Sec. 7, T. 4 N., R. 6 W.

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[7] R. W. Sawyer, "Areal Geology of a Part of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (1924), pp. 318–19.

[8] C. N. Gould, "A New Classification of the Permian Redbeds of Southwestern Oklahoma," *ibid.*, Vol. 8, No. 3 (1924), p. 335.
"Index to the Stratigraphy of Oklahoma," *Oklahoma Geol. Survey Bull. 35* (1925), p. 92.

[9] C. D. Stephenson, "Verden Sandstone of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (1925), pp. 626–31.

[10] C. M. Becker, "Oil and Gas in Oklahoma, Grady County," *Oklahoma Geol. Survey Bull. 40*, Vol. 2 (1930), p. 112.

[11] Norman Meland, "The Verden Sandstone," Oklahoma University thesis, Pt. 2, for Master of Science degree (June, 1922). (Copy in library of University of Oklahoma.)

[12] R. D. Reed and Norman Meland, "The Verden Sandstone," *Jour. Geology*, Vol. 32 (1924), pp. 150–67.

[13] H. D. Miser, *Geologic Map of Oklahoma*, U. S. Geol. Survey (1926).

[14] C. M. Becker, *op. cit.*, Fig. 16, p. 111.
C. D. Stephenson, *op. cit.*, p. 627.
C. N. Gould, *op. cit.*, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, p. 335.
R. W. Sawyer, *op. cit.*, p. 318.

Recently quarries have been opened in the sandstone at many places (Fig. 6). These have revealed features of bedding, cross-bedding, ripple marks, and fossils, some of which have not heretofore

FIG. 6.—Quarry in Verden sandstone in SE. ¼ of Sec. 34, T. 8 N., R. 9 W. The three main beds are separated by thin beds of sandy shale.

FIG. 7. —Edge of single bed of Verden sandstone showing cross-bedding northwestward in SE. ¼ of Sec. 9, T. 5 N., R. 7 W.

been accessible for examination. These and other features of the sandstone that are displayed along its full length of exposure were studied by the writer during a period of 8 days in June, 1936.

STRATIGRAPHY

The Verden sandstone is a pinkish brown, coarse-grained, calcareous rock. It lies within a sequence of regularly bedded orange-red calcareous and gypsiferous fine-grained sandstone, siltstone, and shale, and a few thin gypsum beds that have a total thickness of approximately 120 feet. These beds form the Marlow formation as defined by Sawyer[15] and recently described in detail by Darsie Green.[16] The Marlow forms a portion of the redbeds sequence of Permian age.

The beds in the Marlow formation are remarkably persistent with uniform thickness and character throughout a broad region that according to Green[17] and Russom[18] occupies several counties. Many persistent beds are only a few inches thick and a few beds of bentonitic clay are only a fraction of an inch thick. Some of the thin sandstone beds contain oscillation ripple marks. The main part of the Marlow formation is strikingly much finer-grained than the Verden sandstone. Locally, however, the formation contains coarse grains of chert and quartz that are identical with those in the Verden sandstone. The coarse grains occur in fair abundance in only a few beds, one of which is at the horizon of the Verden sandstone and is widespread. In these beds the coarse grains are thinly scattered through a matrix of fine-grained sediments.

The Verden sandstone occurs from about 85 to 105 feet[19] above the base of the Marlow formation and appears to maintain its stratigraphic position within this thin zone throughout the length of its outcrop.[20] At each of 14 localities, distributed through 20 miles of the sandstone belt, where the contact of the Verden sandstone with the underlying beds was examined by the writer, the coarse-grained sandstone terminates abruptly below on a horizontal bed of soft clay (Fig. 10). The sequence of beds below the Verden at these localities consists of red clay that contains two beds of grayish white gypsifer-

[15] R. W. Sawyer, *op. cit.*, pp. 315–16.

[16] D. A. Green, "Permian and Pennsylvanian Sediments Exposed in Central and West-Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 11 (1936), pp. 1469–71.

[17] D. A. Green, *op. cit.*, p. 1469.

[18] V. W. Russom, personal communication.

[19] The Verden sandstone is only 65 feet above the base of the Marlow formation in Sec. 34, T. 13 N., R. 9 W., according to a letter received recently from V. W. Russom. The Verden sandstone appears to maintain its normal stratigraphic position, however, because persistent key beds several feet below the Verden and other beds above the Verden are also closer to the base of the Marlow here than elsewhere in the region.

[20] D. A. Green, *op. cit.*, p. 1471.
C. D. Stephenson, "Observation on the Verden Sandstone of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (1925), pp. 627–29.

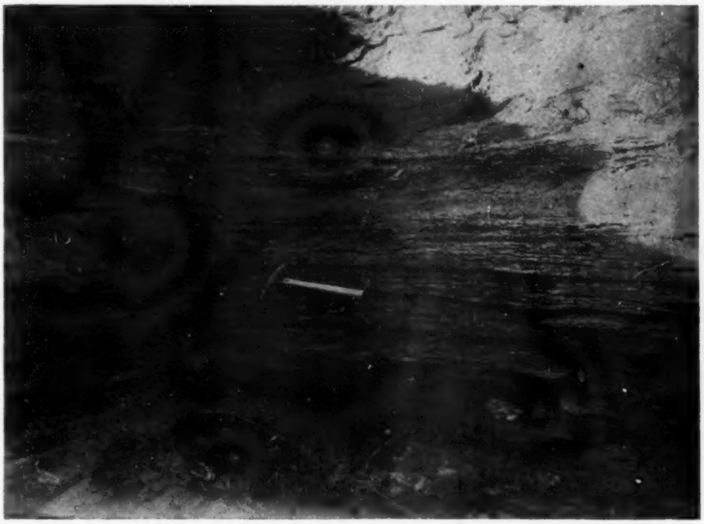

Fig. 8.—Thin-bedded sandy shale and silt beds, lowest of which is about 3 feet above the Verden sandstone in SW. ¼ of Sec. 19, T. 7 N., R. 8 W.

Fig. 9.—Giant ripple marks in Verden sandstone near southeast corner of the SW. ¼, SW. ¼ of Sec. 29, T. 7 N., R. 8 W. Distance from crest to crest (wave length) is about 11 feet; height of crest above trough (amplitude) is about 10 inches; trend of ripple marks is N. 40° W.

ous clay, each 3 to 5 inches thick and separated by a bed of red clay 3 to 3½ feet thick. It appears probable that the beds observed are equivalent at all these localities. In most of the localities the Verden sandstone is separated from the upper gypsiferous clay bed by red shale that is 6 to 12 inches thick, but in a few localities the sandstone is in contact with the upper of the two gypsiferous clay beds.

The beds immediately overlying the Verden sandstone were not seen cleanly exposed except in the SW. ¼ of Sec. 5, T. 9 N., R. 9 W. (Fig. 11), but rocks separated from the Verden sandstone by concealed intervals of only 2 to 3 feet were observed at several localities (Fig. 8). These beds consist of well sorted very fine sand, silt, and clay in horizontal laminae that range from paper thinness to 1/32 inch and more in thickness. Some of the beds contain wave ripple marks.

BEDDING

The Verden sandstone is characterized by coarse-grained beds that commonly range from 8 inches to 2 feet in thickness and are everywhere prominently cross-bedded at steep angles (Fig. 7). The coarse-grained cross-bedded layers that form the main part of the sandstone are interbedded with fine-grained horizontally laminated sandy shale. In most places the sandy shale beds range from paper thinness to 3 inches in thickness, but locally range from 6 inches to a foot or more thick (Fig. 11). They lie with sharply defined contacts horizontally across the edges of the steeply cross-bedded layers of the coarse-grained rock. In some localities, however, no sandy shale was observed between beds of coarse-grained sandstone; there, only the junction of sets of cross beds appears to mark the boundaries of the beds.

COMPOSITION

The coarse-grained beds of the Verden sandstone are composed mainly of rounded, medium to coarse (½ to 1 millimeter), pitted grains of quartz and approximately 3 to 5 per cent of subangular coarse grains of dull reddish and white chert, whose maximum diameters are approximately 4 millimeters. Reed and Meland[21] reported rare grains of microcline in the Verden. The fine-grained sandy shale beds also are composed mainly of angular grains of quartz and chert. Traces of mica occur in the coarse-grained beds and mica is conspicuously more abundant in the sandy shale beds. Even where abundant, mica probably makes up less than 2 per cent of the rock. More than 50 per cent of the rock is calcium carbonate[22] which firmly binds the sand grains

[21] R. D. Reed and Norman Meland, "The Verden Sandstone," *Jour. Geology*, Vol. 32 (1924), p. 155.

[22] R. D. Reed and Norman Meland, *op. cit.*, p. 155.

FIG. 10.—Verden sandstone (about 9 feet thick) and underlying red clay including two thin white gypsiferous clay beds in road cut in southwest corner of Sec. 33, T. 7 N., R. 8 W., 6 miles west of Chickasha. V. W. Russom is standing on red clay that lies between two white gypsiferous clay beds.

FIG. 11.—Verden sandstone in SW. ¼ of Sec. 5, T. 9 N., R. 9 W. Lower ledge of cross-bedded coarse sandstone, marked by hammer, is overlain by horizontally laminated beds of fine sandstone and silt. Top bed is coarse, cross-bedded, and fossiliferous.

into a relatively dense rock. In its large content of calcium carbonate the Verden sandstone is similar to the stone reefs on the coast of Brazil, which are composed of about 30 to 35 per cent calcium carbonate.[23]

The chert grains, which are, in general, coarser than the quartz grains, stand out conspicuously in relief on weathered surfaces of the Verden sandstone and give it one of its main characteristics. The coarsest material occurs at the southeast end of the sandstone belt.

Locally some beds contain cobbles of clay or siltstone, ranging from small pellets to fragments 4 to 5 inches in diameter that are embedded in the sandstone matrix. Some of these cobbles are rounded and others are subangular to angular. South of the farm buildings near the northwest corner of Sec. 19, T. 6 N., R. 7 W., and west of this locality, across the road near the northeast corner of Sec. 24, T. 6 N., R. 8 W., the silt and clay cobbles are particularly abundant in cross-bedded sandstone that is closely associated with relatively thin, horizontally laminated silty shale.

CROSS-BEDDING

The coarse-grained beds of the Verden sandstone are cross-bedded in all exposures examined by the writer. The cross-bedded layers dip at angles ranging from less than 1° to 24°, but commonly range from 10° to 20°. Although the predominant dip of the cross-bedding is northwestward in all exposures observed, the directions of dips in the several beds that make up the sandstone at each single exposure range through a rather broad arc. The writer observed local examples of cross-bedding that dip into each of the four quadrants of the compass. For instance, in the SW.¼ of Sec. 13, T. 7 N., R. 9 W., a mile southwest of Verden, the predominant dip of the false beds is northwestward, but in an area 20 feet in diameter some beds dip northeast, others northwest, others southwest, and still others southeast. Moreover, throughout a distance of 200 feet on the northeast side of the butte in Section 13, the cross-bedded layers dip predominantly southwestward, but elsewhere near by they dip northwestward. Commonly the cross-bedded layers cross a bed at steep angles and end abruptly at the top and base of the bed (Fig. 7), but in many localities the cross-bedded laminae coalesce below with less steeply dipping layers and thus wedge out.

[23] J. C. Branner, "Stone Reefs on the Northeast Coast of Brazil," *Bull. Geol. Soc. America*, Vol. 16 (1905), p. 2.

"The Stone Reefs of Brazil, Their Geological and Geographical Relations," *Bull. Museum Comparative Zoölogy*, Vol. 44 (1904), p. 172.

RIPPLE MARKS

Wave ripple marks, also called oscillation ripple marks, were observed in the Verden sandstone at 11 localities and giant ripple marks were seen at 16 localities. All of the observed ripple marks are in the fine-grained sandy shale beds, although the troughs of the giant ripple marks are cut down into the coarse-grained beds. Irregularly shaped ripple marks, referred to by some geologists as tadpole nests or interference ripple marks, were seen in the fine-grained sandy shale beds at a few localities. The giant ripple marks (Fig. 9) trend parallel with, or depart only a few degrees from, the course of the sandstone belt. They have amplitudes of 6 to 12 inches and the crests vary from 4 to 12 feet apart. Some of the giant ripple marks are asymmetrical in cross section. The small oscillation ripple marks trend in the general direction of the length of the sandstone belt, but in detail range in direction through a wide arc. It may be significant that in several localities the steep flanks of the giant ripple marks face northeastward; also in some localities the ripple-marked upper surface of the sandstone slopes southwestward at angles much steeper than any structural dips observed in the region. In at least one locality the steep slopes of giant ripple marks face southwestward. Giant ripple marks are cleanly exposed in the quarry west of the creek, near the southwest corner of Sec. 18, T. 4 N., R. 6 W., at the southeast end of the ridge in the W. ½, NW. ¼, NW. ¼ of Sec. 26, T. 5 N., R. 7 W., on the ridge whose southeast end is a short distance southeast of the center of Sec. 4, T. 6 N., R. 8 W.

Small wave ripple marks are exposed in the quarry east of the creek, near the southwest corner of Sec. 18, T. 4 N., R. 6 W.; in the quarry near the southeast corner of Sec. 22, T. 5 N., R. 7 W.; in the quarry near the southeast end of the ridge in the SE. ¼ of Sec. 9, T. 5 N., R. 7 W.; in the quarry at the southeast end of the ridge in the SE. ¼ of Sec. 34, T. 8 N., R. 9 W.; and near the southeast end of the west ridge near the center of the N. ½ of Sec. 16, T. 11 N., R. 9 W.; and elsewhere.

SORTING

The sand grains in the Verden sandstone range from particles of clay and silt sizes to 4 or 5 millimeters. Nevertheless, everywhere the grains are sorted into layers in which grains of one size predominate. The cross-bedded parts of the sandstone contain interlaminated coarse- and fine-grained material in layers ½ to 1½ inches, more or less, thick. The sandy shale beds, that are interbedded with the thick

cross-bedded beds, contain sharply defined horizontal laminae composed of very fine sand, silt, and clay particles that are well sorted. The mica flakes, which are relatively abundant in the fine-grained rock, are concentrated on the bedding planes. In the coarse-grained beds it is mainly the alternation of fine- and coarse-grained, cross-bedded layers, which are accentuated by varying intensities of red, that gives the rock a cross-banded appearance. The cross-bedding is made particularly conspicuous on weathered edges of the sandstone on which the alternate fine- and coarse-grained layers stand in relief as ridges and grooves, all dipping at steep angles, as illustrated in Figure 7. The coarse-grained beds of the Verden sandstone are not nearly so well sorted, however, as most beach sands, but are much better sorted than most river sands. The sorting appears to be similar to that the writer has observed in beach sand at Indian River inlet, Delaware, on the Atlantic coast. There, the local sand deposit was transported by the swift tidal currents that flow outward through the inlet. The sand grains range from pebbles to silt, and contain also a few clam shells from 4 to 5 inches in diameter. The sand is sorted into coarse- and fine-grained layers, but the deposit considered as a whole could not be classed as well sorted.

Two small samples from adjacent cross-bedded layers in a hand specimen collected from the Verden sandstone near the northeast corner of Sec. 5, T. 6 N., R. 8 W., were treated with hydrochloric acid, washed, and the residue passed through a set of sieves. Much of the fine material was lost in washing out the acid, but of the sieved portion of the samples 80 per cent of the coarse-grained bed was found to be coarse and medium sand ($\frac{1}{4}$ to 1 millimeter) and 85 per cent of the finer-grained bed was found to be medium sand ($\frac{1}{4}$ to $\frac{1}{2}$ millimeter). These data merely serve to verify the field observations that indicated that the sand is sorted.

FOSSILS

Fossils were observed in 18 localities distributed throughout the length of the Verden sandstone belt, but none has been found in the enclosing Marlow formation. At these localities the fossils do not occur in all beds in the Verden, but are concentrated in a few thin cross-bedded layers of local extent. The fossils consist mainly of small pelecypods and a few gastropods which George H. Girty of the Geological Survey identified as marine forms of Permian age, most of which have been collected also from the Whitehorse sandstone of Oklahoma. The valves occur separately and lie with their convex sides up, which shows that they have been transported. On the other

hand, the edges of the specimens show little wear. The best preserved fossils were observed in a recently opened small quarry in the SE. ¼ of SE. ¼ of Sec. 4, T. 6 N., R. 8 W., 3 miles northwest of Norge.

Girty's report on the fossils is quoted in part.

These four collections from the Verden sandstone have essentially identical faunas and they recall faunally as well as lithologically the Whitehorse sandstone. The fauna of the Whitehorse sandstone, which was described by Beede, is known only at Whitehorse Springs, Oklahoma, and Dosier, Texas, and its vertical range is not known. The similarity of the fauna of the Verden sandstone suggests an age more or less contemporaneous with that of the Whitehorse sandstone, and the correlation should be carefully considered; certainly it is favored by the paleontologic evidence. The collections have been distinguished by the following numbers in the permanent catalogue of Carboniferous localities of the Survey:

8101. SE. ¼ sec. 4, T. 6 N., R. 8 W., Oklahoma.
8102. SW. ¼ sec. 5, T. 9 N., R. 9 W., Oklahoma.
8103. Sec. 16, T. 11 N., R. 9 W., Oklahoma.
8104. SE. ¼ sec. 9, T. 5 N., R. 7 W., Oklahoma.

As represented in these collections, the fauna of the Verden sandstone consists entirely of pelecypods with a few gastropods, and several circumstances make it difficult to prepare faunal lists in the usual way.

The common form by far is a *Pteria*-like shell whose generic characters are best shown by specimens in Lot 8,101, in which it is extremely abundant. Some specimens show the hinge characters which consist of 2 or 3 long lateral teeth parallel to the hinge, and some vertical or oblique cardinal teeth which seem to vary greatly in number and in size on different specimens. These shells clearly belong to the genus which Beede has identified as *Cyrtodontarca*. He has distinguished several species in the Whitehorse fauna on these criteria, and probably all three of Beede's species can be identified in this lot, namely, *C. gouldi*, *C. multidentata*, and *C. parallelodentata*. Shells of this character are abundant also in the three other lots, though less abundant and less well preserved. Few of them show their dentition and consequently can not be classified on the character used by Beede. In fact, it would be difficult to prove that they belong to the same genus, though that can hardly be doubted. On the basis of the size of the anterior lobe and the inclination of the axis there are several other species of this genus in the fauna of the Verden sandstone but they would be undescribed species as the genus *Cyrtodontarca* is known only in the Whitehorse fauna.

The best and therefore the most identifiable specimen of *Pleurophorus* occurs in Lot 8,102. It is certainly not Beede's species, *P. albequus*, but may possibly be the form that he distinguished as the variety *longus*, though it is a much smaller shell. In shape it rather closely resembles *P. subcostatus* of the Pennsylvanian. It also resembles *P. ohioensis* of the Dunkard formation, and less closely, *P. oblongus*. Several other specimens of *Pleurophorus* were collected at the same locality and a few are scattered through the three other lots. No two specimens are exactly alike, but on the other hand, the differences are not so marked that they could be pronounced unquestionably distinct species.

The gastropods are not numerous and their preservation is ill adapted for accurate identification. In Lot 8,104 there is a specimen of *Bulimorpha* which may be Beede's *B. alvaensis*, and a specimen of *Goniasma* (?) which may be *Murchisonia gouldi*. A form resembling Beede's *Orthonema texanum* is found in Lots 8,103 and 8,104 together with a few other gastropods which seem not to have been distinguished in the Whitehorse fauna.

The fauna of the Verden sandstone is a difficult one to treat in the matter of distinguishing and identifying its specific units, and the way in which the specimens are preserved . . . has added to that inherent difficulty. To do the job right would mean a long and trying investigation. As matters stand, the Verden fauna shows a marked resemblance to the Whitehorse fauna, though as represented in these collections, it is by no means so varied. Beede calls his Whitehorse fauna upper Permian and I am content to let it go at that. It is worthy of note, however, that it shows no resemblance whatever to the Guadalupian faunas, and this is almost equally true in its relation to the better known Permian faunas of the Mississippi Valley such as those of Kansas.

As regards the habitat of the fauna of the Verden sandstone, if its relations to the fauna of the Whitehorse sandstone are what I am confident they are, the fauna is marine beyond question. Even without this evidence I would feel little hesitation in claiming it as a marine fauna, though I might not be quite so downright about it.

MANNER OF DEPOSITION

The extreme narrowness of the Verden sandstone in contrast to its length, when considered with a few of its other features, confines the discussion of its mode of origin to two general processes of deposition: (1) deposition by a stream flowing in a narrow channel, or (2) deposition by waves and longshore currents as some form of barrier beach, also called an offshore bar.

Reeves[24] advocated the theory that the sandstone occupies the valley of a Permian stream, but that it was deposited by a tidal current that flowed northwestward from the sea up the stream's course. Reed and Meland[25] concluded that the sandstone was deposited by a single flood that flowed northwestward in the channel of a distributary of a desert river. Sawyer[26] stated that "the manner of formation of this bed is in doubt . . . but it would seem to mark an old shore line of a body of water" in Marlow time.

Several of the features of the Verden sandstone, which are summarized in the following paragraphs, appear to indicate the manner in which it was deposited.

1. The distribution of the sandstone body in a long narrow belt

[24] Frank Reeves, "Geology of the Cement Oil Field, Caddo County, Oklahoma," *U. S. Geol. Survey Bull. 726* (1921), p. 51.

[25] R. D. Reed and Norman Meland, "The Verden Sandstone," *Jour. Geology*, Vol. 32 (1924), p. 167.

[26] R. W. Sawyer, "Areal Geology of a Part of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (1924), pp. 318–19.

lacking sharp bends or meanders is more like the general distribution of shore features, such as bars, than the course of a stream channel, although it is not necessarily different from the nearly straight courses of streams on tidal flats.

2. The marine fossils that occur abundantly distributed through the entire length of the sandstone belt suggest that it was deposited in a marine environment. The many thousands of specimens whose edges show little or no wear indicate that the fossils were not transported through long distances. Therefore, they appear to have lived near by, and in the environment that prevailed during the deposition of the sand.

3. The persistence of thin beds, including gypsum, that are associated with the Verden sandstone throughout parts of several counties suggests that these associated sediments were deposited in a shallow water body where waves and currents spread the sediment in thin layers widely over the bottom. The persistent gypsum beds indicate also that the sea water was highly concentrated at times.

4. The occurrence of the Verden sandstone at a single stratigraphic position, throughout at least 40 miles of its course, suggests that it, too, was deposited in a body of water on whose bottom sediment had accumulated in essentially horizontal layers.

5. The undisturbed condition of the soft clay and gypsum beds immediately beneath the steeply cross-bedded, coarse Verden sandstone also indicates that the coarse sand was deposited in a large water body. A stream having a current strong enough to transport the coarse quartz and chert grains of the Verden sandstone and deposit them in short beds dipping at steep angles would gouge pits in the underlying soft clay and silt beds and dump its load of unsorted sediment in irregularly cross-bedded lenses. On the other hand, the extension of a sand bar by addition to its end made by longshore currents or by waves causing beach drifting would not necessarily disturb the bottom sediments upon which the bar was being extended. Many examples in which bars are being elongated by additions of sand at one end can be cited on our modern coasts. A few examples are Sandy Hook, New Jersey; Long Island, New York; and Cape Cod, Massachusetts.

6. The sorted character of the Verden sandstone and the small content of silt and clay in the coarse cross-bedded beds are features that are characteristic of marine near-shore beach deposits. On the other hand, stream deposits are commonly poorly sorted and contain much silt and clay intermingled with coarse sediment. It is difficult to conceive of a stream that apparently flowed only at two widely differ-

ent velocities in alternating sequence such that at one time it would deposit the relatively coarse sand in steeply cross-bedded thick beds and at another time the well sorted fine-grained sand and silt in horizontally laminated thin beds.

7. There can be little doubt that the oscillation ripple marks that trend approximately parallel with the course of the Verden sandstone belt were produced by the to-and-fro action of waves. River currents produce asymmetrical ripple marks that trend in general at right angles to the course of the stream. Ripple marks produced by stream currents should, therefore, trend across the sandstone belt. The giant ripple marks which uniformly trend parallel with the sandstone belt were produced by forces that acted approximately at right angles to the direction of the currents that deposited the steeply cross-bedded layers of coarse sand. They could have been produced by waves that struck the shore approximately at right angles and it appears logical to conclude that they were probably so formed.

8. The occurrence of the Verden sandstone type of coarse quartz and chert grains in the fine-grained sandstone and silt beds of the Marlow outside the course of the sandstone belt but at its horizon, is not unusual for sediments deposited near shore in a large water body.

It is the writer's conclusion that the Verden sandstone was deposited as some type of a bar, or a closely related series of bars; it probably represents a spit, or a closely related chain of spits, that was extended across the mouth of a bay on the shore of a shallow sea. That the main water body lay on the southwest side of the Verden sandstone belt is suggested by the southwesterly slope of the upper surface of the sandstone and the steep northeasterly slopes of the giant ripple marks observed at a few localities. The close similarity of the Marlow strata on both sides of the sandstone belt suggests that the bay was many miles in extent and that the deposition of sediment within the bay differed little from that near shore in the main water body.

The main cross-bedded beds of the sandstone are believed to have been laid down by longshore currents that were active periodically during storms. These currents elongated the bar (or bars) in a northwesterly direction by adding material to its northwest end. During quiescent periods gentle waves and tides spread fine mud over the near-shore bottom and over the newly formed bar. In the Verden sandstone the mud deposits are represented by the fine-grained horizontally laminated thin beds that are interbedded with the coarse-grained, cross-bedded rock. It is probable that the bar was submerged in shallow water most of the time. During periods of moderate weather the ripple marks were probably formed by the action of waves that struck the shore nearly at right angles.

The cobbles of siltstone that were observed at several localities are composed of material similar to that of the silty shale beds and are associated with them in such a manner as to leave little doubt that they were derived from them. The cobbles appear to show that at least the uppermost part of the bar was periodically above water. It is probable that during some of these periods of emergence the newly deposited mud layers were temporarily dried, hardened by exposure, and were cut by mud cracks. Succeeding storm waves broke up the dried sediment into chunks which were transported short distances and redeposited along with coarse sand that was being carried along the bar. The angular shapes of some of the cobbles indicate that they were not transported more than a few feet.

The position of the Verden sand bar (or bars) in relation to the shore and sea may have been somewhat similar to that of the long bar that lies across the mouth of Pensacola Bay on the Florida coast (Fig. 12). It is believed, however, that transportation of sand by long-shore currents greatly predominated over wave transportation on the Verden shore but that these processes are probably more equally balanced on the Pensacola shore.

The waves and currents that wash a seashore sort the near-shore material, concentrate the coarser grains in the sand bars, and spread much of the finer sediment over the near-by sea floor and bottoms of the lagoons that commonly separate the bars from the land. The sorting of the material is never perfect, however, and some coarser grains similar to those concentrated in the sand bars remain thinly scattered in the fine sediment in the lagoon and on the near-shore sea floor. It is probable that such a process accounts for the occurrence of Verden-like coarse quartz and chert grains in the silty sandstone beds of the Marlow formation that occupy the position of the Verden sandstone on both sides of the sandstone belt.

The Verden-like sandstone that occurs at the horizon of the Verden in many localities in an area about 5 miles wide in T. 9 N., R. 9 W., described by Russom[27] may have been deposited as the shore line shifted to and fro, or may have been deposited by strong currents and waves that broke some distance off shore.

STONE REEFS OF BRAZIL

So many features of the Verden sandstone are similar to those of the stone reefs on the coast of Brazil, which Branner[28] says are lithified

[27] V. W. Russom, personal communication.

[28] J. C. Branner, "Stone Reefs on the Northeast Coast of Brazil," *Bull. Geol. Soc. America*, Vol. 16 (1905), pp. 2–4.

Idem, *Bull. Museum of Comparative Zoölogy*, Vol. 44 (1904), pp. 51, 109, 173, 344–45.

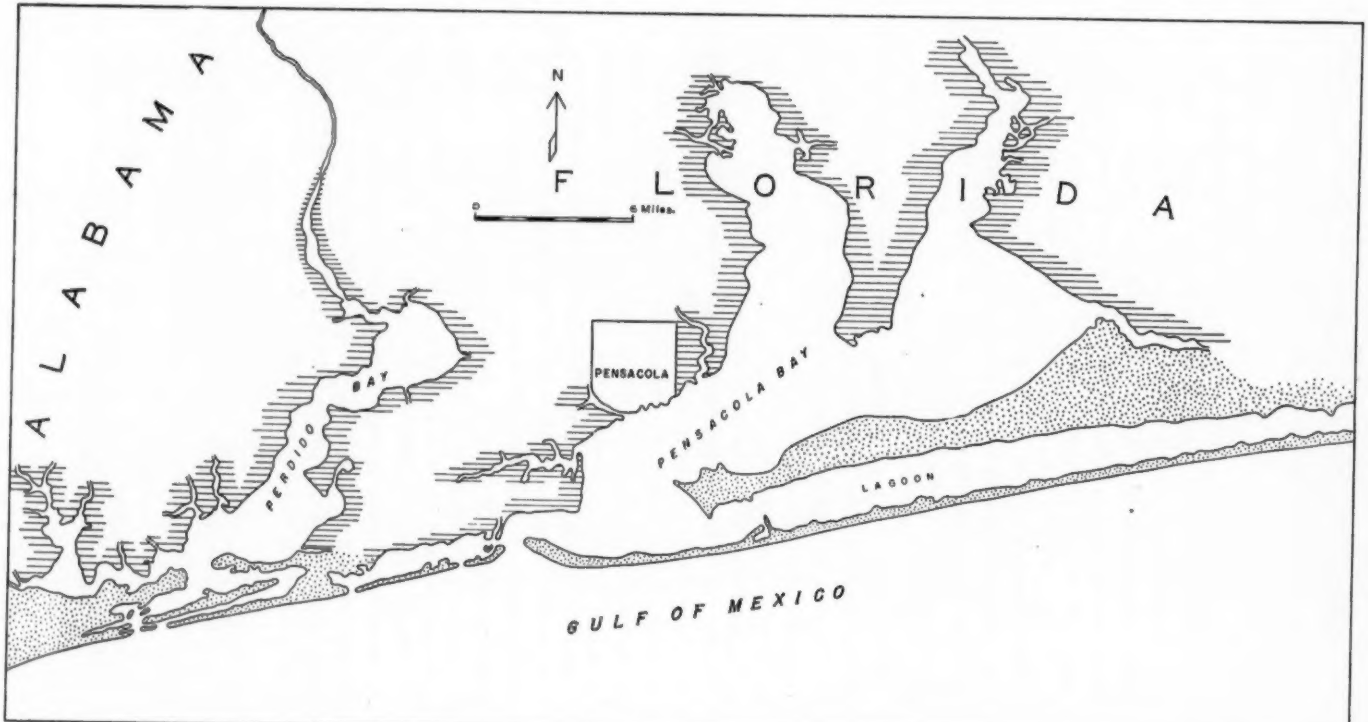

FIG. 12.—Sketch of part of Gulf coast of Florida showing bays enclosed by bars. (After U. S. Coast and Geodetic Survey Chart 1265.)

marine spits, that Branner's description of these unique coastal reefs is briefly summarized here. The stone reefs form an intermittent chain 1,250 miles long. Single reefs are from a few paces to 8½ miles long, 15 to 500 feet or more wide, and 9 to 12 feet thick. Their courses are nearly straight; where crooked the curves are gentle. In many of the reefs one end is connected with the land and the reef extends across the mouth of a stream or estuary, forming a perfect natural breakwater behind it. They stand about flush with the water at high tide, while at low tide they are left exposed like long, low, flat-topped walls (Fig. 4). The tops and many beds of the reefs slope seaward at about the same angles as the tops and beds of the present beaches. The upper surfaces of the stone reefs are marked by longitudinal ridges; the bases appear to be horizontal. False bedding at steep angles is common; a maximum angle of 37° was observed. The reefs are composed of beach sand and gravel, similar to the unconsolidated beaches near by, but in addition contain about 35 per cent calcium carbonate, which binds the sand and gravel into a firm hard rock. The rock contains fossil shells of the various mollusks now living along the coast. The shells are not evenly distributed through the rock, but are abundant in some layers and almost or quite wanting in others.

SOURCE OF VERDEN MATERIALS

The quartz and chert grains of the Verden sandstone were probably derived by wave action from beds of quartz-and chert-bearing conglomerate in the Duncan sandstone that lies immediately below the Marlow formation. The Marlow formation overlaps the Duncan southward in this part of Oklahoma[29] and according to Green[30] the conglomerate beds were exposed locally on anticlinal ridges as late in Marlow time as the Verden sandstone deposition. That the southeast end of the exposed sandstone belt was near the source of the material is indicated by the very coarse quartz and chert grains in the sandstone there. It appears not improbable, however, that sediment was derived from several localities along the course of the sandstone belt, was brushed up from the bottom by the waves and currents, sorted and redeposited on the bars.

ORIGIN OF CALCIUM CARBONATE

Branner[31] believed that the stone reefs of Brazil represent marine spits whose upper beds, 3 to 4 meters thick, were lithified by the depo-

[29] D. A. Green, "Permian and Pennsylvanian Sediments Exposed in Central and West-Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 11 (1936), pp. 1470–71.

[30] *Idem*, oral communication.

[31] J. C. Branner, "Stone Reefs on the Northeast Coast of Brazil," *Bull. Geol. Soc. America*, Vol. 16 (1905), pp. 2–3, 7–10.

sition of calcium carbonate and minor amounts of magnesium and iron soon after they were formed. He believed that fresh and brackish water in the lagoons and estuaries that lay back of the spits was rendered acid by the decomposition of the vegetation that accumulated in the marshes. The acid-laden water percolated part way through the loose sand of the spits and dissolved some of the calcium of the shell fragments and calcareous plant particles that were abundant in the sand. As the calcium-laden water percolated farther through the sand and came in contact with the sea water that occupied the seaward side of the bars the calcium carbonate was redeposited in the interstices between the sand grains. The rain water that fell upon the beaches and passed downward through the sand dissolved calcium from the shell fragments and calcareous plant fragments in the upper part of the sand bar, carried it downward in solution and redeposited it where it came in contact with the water-saturated sand. The widths of the stone reefs are controlled mainly by the distance the calcium-laden water percolated through the sand bars.

Although no specific investigation of the origin of the calcium carbonate that forms about 50 per cent of the Verden sandstone was made, a portion of it may have originated in a manner similar to that advocated by Branner for the origin of the calcium carbonate of the stone reefs. It was pointed out by Miser[32] that, inasmuch as the total volume of calcium carbonate in the Verden sandstone greatly exceeds the probable total pore space of the unconsolidated beach sand, much of the calcium carbonate must have been deposited originally in granular form along with the grains of quartz and chert. Doubtless the main source of the granular calcareous material was the shells that had accumulated along the shore and had been pulverized by the grinding action of the waves. The fossils that are preserved in abundance in the Verden sandstone apparently represent only a very small part of the total shells that were dropped along the shore. Also, Knappen[33] suggested that because the sea water was highly saturated (indicated by gypsum beds in the Marlow formation), a considerable portion of the calcium carbonate of the Verden sandstone was probably precipitated directly out of solution in the sea water by the action of breakers which aerated the water along the growing sand bars. It is probable that each of the processes described contributed a part of the calcium carbonate of the Verden sandstone.

[32] H. D. Miser, oral communication.

[33] R. S. Knappen, oral communication.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to V. W. Russom of the Sinclair Prairie Oil Company, Darsie A. Green of the Pure Oil Company, and H. L. Griley of the Sun Oil Company, who gave the writer much stratigraphic information about the Marlow formation and associated beds, furnished maps showing the outcrops, and read the manuscript; to H. D. Miser and W. H. Bradley of the Geological Survey and to R. S. Knappen of the Gulf Oil Corporation and R. W. Sawyer who read the manuscript and made many criticisms and suggestions.

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AREAL VARIATION OF ORGANIC CARBON CONTENT OF BARATARIA BAY SEDIMENTS, LOUISIANA[1]

W. C. KRUMBEIN[2] AND L. T. CALDWELL[3]
Chicago and DeKalb, Illinois

ABSTRACT

Bottom sediments were collected from part of Barataria Bay, a tidal lagoon on the Mississippi delta. The organic carbon content of the samples was determined by a dry combustion method. The analytical data were used to prepare a map of the areal distribution of organic carbon in the environment. These data are correlated with the size attributes of the sediments; in general, the finest sediments have the largest content of organic carbon. The relation between average size and organic carbon appears to be exponential.

The data are related to recent work on "shoestring" oil sands. The pattern of sediments in Barataria Bay supports earlier work by providing a suitable areal variation for the origin of the oil in the finer sediments, and its accumulation in the coarser sediments of the same general environment, by means of channels which serve as natural conduits for migration.

INTRODUCTION

The organic carbon content of sediments in its relation to the origin of petroleum has received considerable attention in the literature. The present paper describes the organic carbon content of bottom sediments from Barataria Bay in terms of its areal variation, and in relation to the average size of the sediment. A fairly complete set of samples was originally collected for a study of the size characteristics of the sediment as an index to environmental conditions. As work progressed it was found that the samples lend themselves also to a consideration of other sedimentary characteristics.

The writers are indebted to Miss Esther Aberdeen[4] for collecting the original samples. Miss Aberdeen collaborated with the senior writer in an earlier paper[5] on the size properties of the sediments. The following section on the collection of the samples is taken from the earlier paper, with minor changes, and is included to make the present report self-contained. The laboratory determinations in the present study were made largely by the junior writer; the senior writer is responsible for the illustrations, the organization, and the method of presentation.

[1] Manuscript received, December 2, 1938.

[2] University of Chicago.

[3] Northern Illinois State Teachers College.

[4] Wellesley College, Wellesley, Massachusetts.

[5] W. C. Krumbein and Esther Aberdeen, "The Sediments of Barataria Bay," *Jour. Sed. Petrology*, Vol. 7 (1937), pp. 3–17.

Barataria Bay lies approximately 50 miles south-southeast of New Orleans, Louisiana. The Mississippi River flows about 10 miles east of the bay proper. A canal connects river and bay near New Orleans; other than this no streams enter the bay. The bay itself is a tidal lagoon, with a main passage about one-fourth of a mile wide, opening southward into the Gulf of Mexico. Two smaller passes have recently opened through the barrier, and a small delta is rapidly being built in a projecting southeasterly arm of the bay, from sediments washed through the passes during storms on the Gulf. The main bay itself is more or less rectangular, slightly wider at the north than at the south, and the east, west, and north shores of the bay are a series of islands rather than mainland. Several small islands interrupt the surface of the bay, and many slightly submerged oyster reefs are to be found here and there.

COLLECTION OF SAMPLES

The present study is based on 98 samples collected in the bay and its immediate vicinity. The sampling was confined to the southern part of the bay, where presumably the greatest variation in sedimentary characteristics is found. Figure 1 is a map of this part of the bay, showing the sample localities, each of which is identified by a sample number. Several depth contours are given, which show the main channels in the bay. Most of the bay is shallow, varying from 1 to 5 feet in depth. In the central part of the bay, however, is a channel varying from 6 to 18 feet deep, which extends from Barataria Pass (at East Point) to the northern end of the area. Just within the pass itself the greatest depth is 165 feet, which attests to the strength of the currents that surge into and out of the bay. The channel extends outward into the Gulf, and terminates in a broad delta-like extension, as shown by the outermost depth contour in Figure 1.

The samples were collected on a rough grid pattern; islands and channel lights were used for bearings. A clam-shell snapper was used for samples in the deeper waters, and an oyster rake in shallow water.

MECHANICAL ANALYSIS OF SAMPLES

The pipette method[6] was used in the analysis of all except a half dozen samples whose particles lie entirely within the range of sieve sizes. The pipette analysis involved the use of an air-dried test sample weighing about 25 grams. The sample was dispersed in N/100 sodium oxalate solution. After dispersion the sample was passed through a sieve with meshes of 0.061 millimeter to separate the sand. The finer

[6] W. C. Krumbein, "The Mechanical Analysis of Fine-Grained Sediments," *Jour. Sed. Petrology*, Vol. 2 (1932), pp. 140–49.

material was pipetted, the sand was dried and sieved, and the two parts of the analysis were combined into a single table of percentages. The detailed steps in the dispersion procedure are described elsewhere.[7]

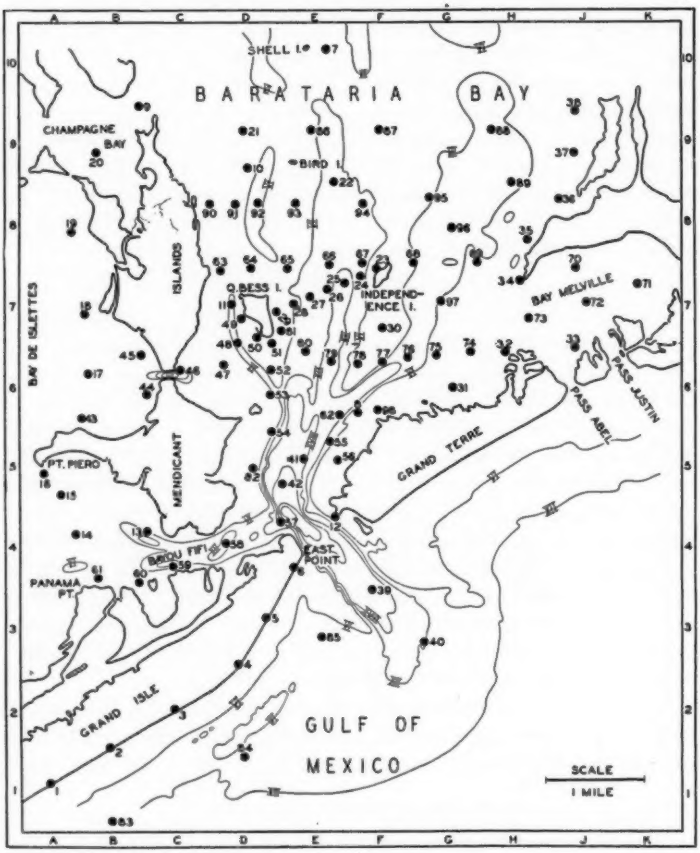

FIG. 1.—Southern part of Barataria Bay, showing location and number of samples. Roman numerals refer to depth of water in feet.

The mechanical analysis data are summarized from the earlier paper in Table I. Average size is expressed as the phi median[8] rather

[7] W. C. Krumbein, "The Dispersion of Fine-Grained Sediments for Mechanical Analysis," *Jour. Sed. Petrology*, Vol. 3 (1933), pp. 121–35.

TABLE I

CHARACTERISTICS OF BARATARIA BAY SAMPLES

Sample	*Phi Median*	*Carbon Percentage*	*Type*	*Sample*	*Phi Median*	*Carbon Percentage*	*Type*
1	2.80	0.10	I	51	3.21	0.70	II
2	2.82	0.05	I	52	3.37	0.68	II
3	2.80	0.01	I	53	3.25	0.58	II
4	2.80	0.00	I	54	3.38	0.58	II
5	2.88	0.00	I	55	3.35	0.73	II
6	2.85	0.06	I	56	2.42	*	V
7	4.20	0.96	III	57	3.10	0.50	II
8	6.90	2.67	V	58	4.56	3.78	IV
9	4.70	0.87	IV	59	2.96	0.65	II
10	3.33	0.39	II	60	3.18	0.92	II
11	4.00	0.45	III	61	3.62	1.09	III
12	2.97	0.15	I	62	4.00	0.72	III
13	4.50	1.65	IV	63	6.05	2.10	V
14	3.40	0.58	II	64	4.35	1.38	III
15	3.75	0.73	III	65	3.36	0.82	II
16	4.40	1.10	IV	66	4.28	1.40	III
17	4.28	1.00	III	67	4.18	1.57	III
18	4.80	1.80	IV	68	5.00	1.67	IV
19	4.90	1.35	IV	69	4.83	1.50	IV
20	5.50	1.51	I	70	5.93	1.99	V
21	3.42	0.49	II	71	4.20	0.69	III
22	3.11	0.41	II	72	3.12	0.20	I
23	4.46	1.51	IV	73	3.21	0.10	I
24	3.84	0.96	III	74	6.47	2.11	V
25	4.03	1.36	III	75	3.82	1.08	III
26	4.00	1.82	III	76	4.75	0.31	IV
27	3.75	1.30	III	77	3.50	0.25	III
28	3.30	0.74	II	78	3.96	0.67	III
29	3.70	1.24	III	79	3.60	0.79	III
30	3.80	0.60	III	80	3.40	0.38	II
31	3.14	0.34	II	81	3.40	0.14	II
32	4.35	0.85	IV	82	3.70	0.42	III
33	4.30	0.73	III	83	3.46	0.20	I
34	5.65	1.57	V	84	3.38	0.06	I
35	4.91	0.58	IV	85	2.87	0.04	I
36	5.08	0.52	IV	86	3.86	0.55	III
37	5.75	0.75	V	87	3.80	0.54	III
38	5.07	1.01	IV	88	3.70	0.46	III
39	3.30	0.58	II	89	3.74	0.78	III
40	4.15	0.94	III	90	4.92	1.14	IV
41	4.30	0.85	IV	91	3.88	0.50	III
42	3.36	0.28	II	92	4.82	1.36	IV
43	5.65	7.60	V	93	3.41	0.36	II
44	5.68	2.25	V	94	3.61	0.54	III
45	4.66	1.86	IV	95	3.69	0.41	III
46	7.05	1.79	V	96	3.46	0.67	II
47	4.44	1.83	III	97	3.65	0.70	III
48	4.76	1.37	IV	98	3.62	0.48	III
49	3.50	0.61	II				
50	3.30	0.58	II				

* No carbon analysis; entire sample used for size analysis.

[8] W. C. Krumbein, "The Use of Quartile Measures in Describing and Comparing Sediments," *Amer. Jour. Sci.*, Vol. 32 (1936), pp. 98–111.

than as diameters in millimeters. The phi median is simply a logarithm of the median size in millimeters. It is not appropriate to discuss the complete theory of the phi notation here.[9] Essentially it involves the substitution of a new variable, ϕ for diameters in millimeters, in accordance with the equation $\phi = -\log_2\xi$, where ξ is the diameter in millimeters. Thus ϕ is the negative log to the base two of the diameter in millimeters, and physically a change of $+1$ in the phi value means that the diameter value decreases by half.

The use of the phi notation converts the Wentworth grade scale into a series of equal intervals, such that each class limit is an integer, and in such a manner that the values increase with decreasing grain size. Thus for diameter values of 2, 1, $\frac{1}{2}$, $\frac{1}{4}$ millimeters, the corresponding phi values are -1, 0, $+1$, $+2$, respectively. The phi notation was developed to afford an independent variable useful for statistical computations, and so designed that the statistical values are expressed directly in Wentworth grades as units. In practice, the phi notation permits the use of ordinary arithmetic graph paper instead of logarithmic paper, with no change in shape of plotted curves, and with direct arithmetic interpolation. Any common statistical device may be used and expressed in the phi notation. Moreover, the resulting logarithmic values may be used directly in the interpretation of the sediment, or they may be converted to their diameter-equivalents if desired. The diameter-equivalents of the phi medians in Table I are indicated on Figure 4, in a later section of this paper.

The mechanical analysis data were used to draw cumulative curves of the sediments, and to compute statistical measures in the phi notation, using median and quartiles. The 98 cumulative curves, plotted on a single sheet, grouped themselves into five bands of curves.[10] This distribution was used to subdivide the sediments into five types. The five types are not sharply differentiated from each other, but unquestionably represent a gradational series. It is convenient to discuss the sediments on the basis of type, because each type has certain average characteristics. Table I includes the classification of the samples according to type.

Figure 2 is a map of sediment distribution in Barataria Bay. The individual samples have been assembled into the five types, and the several areas on the map indicate the distribution of types over the bay bottom. Table II is a brief summary of the average characteristics of each type, for convenience in interpreting the map.

[9] W. C. Krumbein, "Application of Logarithmic Moments to Size Frequency Distributions of Sediments," *Jour. Sed. Petrology*, Vol. 6 (1936), pp. 35–47.

[10] See Krumbein and Aberdeen, *op. cit.* (1937).

TABLE II

CHARACTERISTICS OF TYPE SEDIMENTS

Type	*General Character*	*Average Phi Median*	*Average Median in Mm.*	*Average Percentage of Sand*	*Average Percentage of Silt*	*Average Percentage of Clay*
I	Sand	2.85	0.139	100	0	0
II	Silty sand	3.37	.093	75	25	0
III	Silty sand	3.80	.072	52	38	10
IV	Clay-silt	4.70	.040	20	65	15
V	Clay-silt	5.93	.017	10	65	25

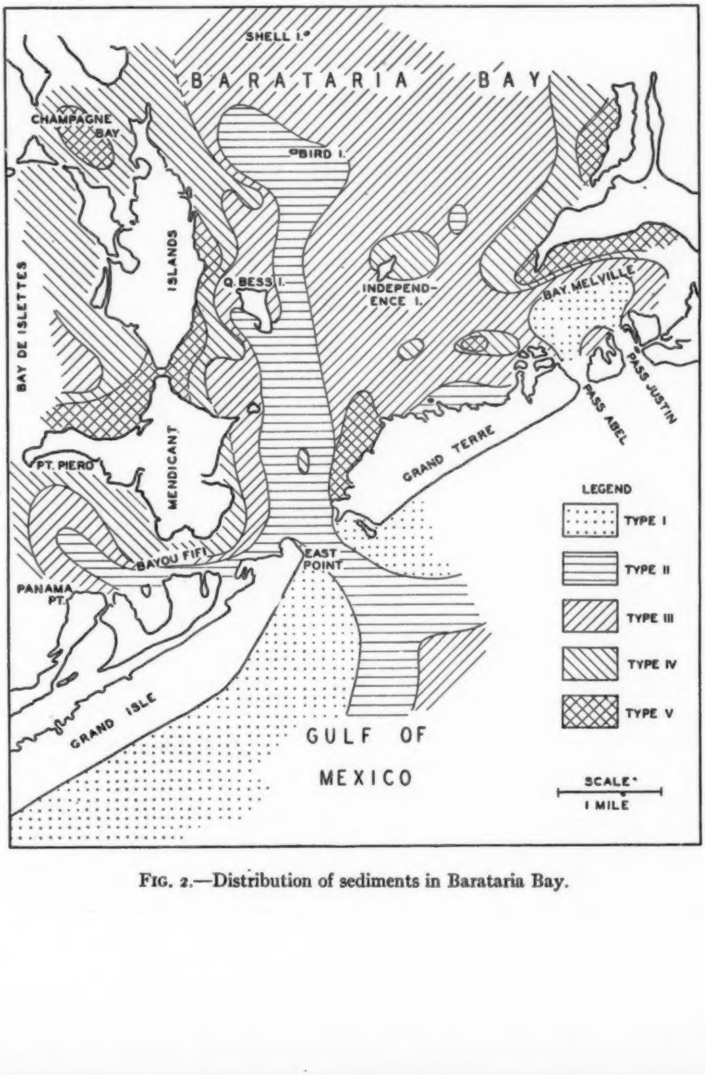

FIG. 2.—Distribution of sediments in Barataria Bay.

Type I sediments are typical beach sands, well sorted. They extend along the shore of the Gulf, and comprise the barrier beaches themselves. In addition, deltas of sand extend into Bay Melville from material washed through passes Abel and Justin. Type II sediments are silty sand, somewhat finer and less well sorted than type I. They extend as a narrow zone from the Gulf through Barataria Pass and into the bay proper, between Queen Bess and Independence islands. In general this distribution agrees with the main channel shown in Figure 1. Local areas of type II also lie along the inner shores of Grand Isle and Grand Terre. The former is attributed to the channel along Bayou Fifi, and the latter is attributed mainly to the drifting of wind-blown sand into the bay from the barrier beaches.

Type III sediments are composed about equally of sand and silt, and are less well sorted than types I and II. They are widely distributed over the shallow parts of the bay, adjacent to the main channels, and in the zones of comparatively quiet water. Of the 98 samples analyzed, 33 are type III, which may accordingly be considered as the "average sediment" of the environment. Type IV sediments are definitely fine-grained, less sorted than the preceding types, and generally darker in color due to increasing amounts of organic carbon. Type V sediments are the finest and least well sorted of all, and they are generally darkest in color. Types IV and V lie away from the channels in areas of shallow, quiet water, generally fringing the low islands which define the bay. An interesting example of the response of the sediments to environmental conditions is shown by the area of type V sediments along the western edge of Grand Terre, just inside the main channel. This accumulation is apparently due to the slow reverse currents generated by the waters surging into and out of the bay, and is thus a "shadow zone" of fine material in the lee of the barrier.

In a broad way the distribution of sediments in the environment may be correlated with the depth contours of Figure 1. The coarsest and best sorted sediments are found in the zone of breaking waves along the beach; these grade into more silty sand distributed along the main channel of the bay, where the most pronounced currents move back and forth. Finally, over the shallow part of the bay, and especially in the vicinity of the low islands, the sediments become successively finer and less well sorted. The distribution of sediments thus disclosed (Fig. 2) may be referred to as the "environmental pattern" of the bay in terms of size properties. It is interesting to note that this pattern, showing the essential features of sedimentary response to environment, was adequately developed by mechanical analysis alone.

ANALYSIS OF ORGANIC CARBON CONTENT

In addition to mechanical analysis, the samples were analyzed chemically to determine the percentage of organic carbon. The analyses were performed with a combustion train set up in accordance with the method of Popoff.[11] A pyrex tube in a thermostatically controlled electric furnace was used for the combustion. A weighed quantity of the powdered sediment was placed in a porcelain boat, and a stream of oxygen was passed through the tube. The ordinary battery of absorption tubes was used for purifying the oxygen and for removing all products of combustion except the CO_2, which was collected in an Askarite tube. The temperature was controlled for the complete combustion of the organic matter, without decomposing the calcium carbonate minerals. The optimum temperature for these conditions is slightly below 800°C.,[12] and was checked by a series of tests on material of known composition. Many of the samples were run in duplicate as a check on the results; a few samples, which showed anomalous amounts of carbon, were run in triplicate. Checks were consistent to an order of magnitude of about 0.2 per cent of weight of dry sediment.

The shell material in some of the samples apparently interfered to a slight degree with the accuracy of the results, inasmuch as the organic matter in the shells was oxidized, and hence increased the percentage of carbon slightly. This was found to be the fact among some of the sands, which showed small amounts of organic carbon, apparently from the decomposition of the shells. It is not considered to be a serious error in general, however. There also were two samples which showed much higher carbon percentages than the other samples. Whereas the range of organic carbon extended from 0 to about 2.5 per cent in most samples, one sample showed 3.8 per cent, and another more than 7 per cent. These two results are so far out of line with the usual samples that they have been considered as erratic, and while they are shown in the final results, no inferences are made regarding them.

The results of the chemical analyses, expressed as percentage of organic carbon by weight, are included in Table I.

The percentage of organic carbon in each sample was plotted on a map of the bay, each value at its corresponding sampling point. The area was then divided into groups of samples having less than 0.5 per cent of organic carbon, from 0.51 to 1.00 per cent of carbon, and so on, the last group for samples containing more than 2 per cent.

[11] S. Popoff, *Quantitative Analysis* (1927), 2nd ed., New York.

[12] S. Popoff, *op. cit.*, p. 190; I. M. Kolthoff and E. B. Sandell, *Textbook of Quantitative Inorganic Analysis* (1936), pp. 330–31.

The corresponding contour lines afford a basis for dividing the bay into areas as shown on the map of Figure 3.

The legend of Figure 3 indicates that the sediments of lowest organic carbon content extend as a belt along the gulf coast of the

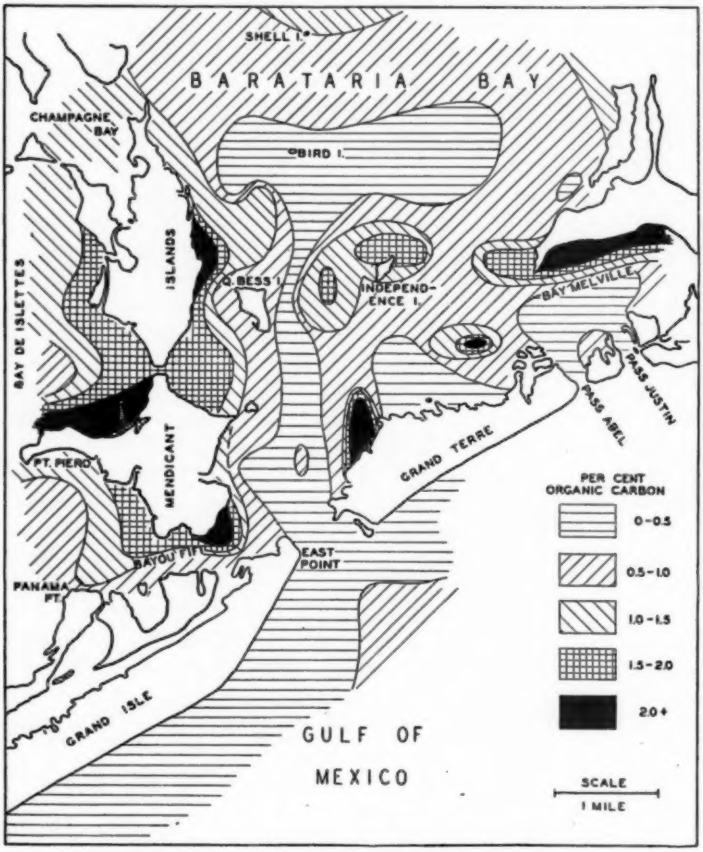

FIG. 3.—Distribution of organic carbon in Barataria Bay.

barrier beaches, and penetrate into the bay through the several passes. A narrow zone extends through the center of the bay between Queen Bess and Independence islands, and widens out over a larger area on the north. Most of the bay is covered with sediments ranging from 0.5 to 2.0 per cent of organic carbon, and the areas having more

than 2.0 per cent (shown in black) are confined to zones fringing the low islands which define the bay. Two exceptional occurrences of high carbon may be noted. One is in the channel at Bayou Fifi, and the other lies north of Grand Terre. The former is probably an erratic sample; the latter correlates with fineness of the sediments at that point, and seems to be attributable to circulatory conditions among the several channels through the barrier.

RELATIONS BETWEEN SIZE AND CARBON CONTENT

A comparison of Figures 2 and 3 shows several interesting parallels. The zones of lowest carbon content include all of types I and II sediments, and some of type III, especially in the upper part of the bay, where the zone widens out near Bird Island. Sediments having between 1 and 2 per cent of carbon constitute most of types III and IV sediments, and the samples of highest carbon content, shown in black, agree in their general distribution with type V. This correlation even extends to the "shadow zone" at the end of Grand Terre, which was mentioned earlier.

The general parallelism of the size and organic carbon patterns is significant, it seems to the writers, because the two sets of data are independent, and were determined by separate analysts. It seems safe to conclude that the environmental pattern is impressed on a number of sedimentary characteristics, so that its essential nature may be brought out by any of several approaches.

It is also interesting to consider the relation between size and organic carbon, independent of areal distribution. Figure 4 is a scatter diagram of the relation between organic carbon content in percentage, and size expressed as the phi median. The corresponding diameter values are shown along the top of the graph, for direct comparison.

The five types of sediments are distinguished from one another by appropriate symbols, to indicate the spread of data in each group. As the chart is followed to the right (toward smaller average sizes) the carbon content increases in general, but there are many deviations in detail. That is, as the average carbon content increases, the spread of individual percentages also increases. Thus type II sediments vary in carbon content from 0.2 to 0.9 per cent, but type III sediments vary from 0.3 to 1.8 per cent.

From a statistical point of view it is interesting to consider the average relation between size and carbon content. For this purpose the centers of gravity of each group of observations were computed[13]

[13] The center of gravity, or *centroid*, of each group is found by computing the arithmetic means of the size and carbon content of each group. For example, the average phi median of group I is 3.0, and the average carbon content of the same group is 0.08 per cent. These values determine the location of the triangle for group I.

and plotted as triangles on Figure 4. The centers of gravity lie approximately on a straight line, as indicated. It is realized that the number of samples in each group varies, so that corresponding weights should be assigned to the centroids, but as a first approximation the linear function is interesting. It will be recalled that the phi median is a logarithm of size in millimeters, so that a linear relation between organic carbon content and the logarithm of size means that the corresponding function between size in millimeters and organic carbon content is exponential.[14] Trask[15] reports a similar relation from his study of ancient and recent sediments in California.

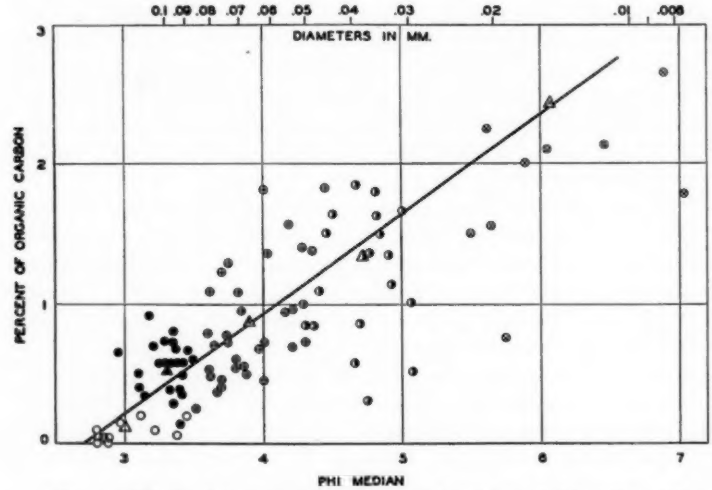

FIG. 4.—Relation between percentage of organic carbon and phi medians of Barataria Bay samples. White circles, type I; black circles, type II; circles with cross, type III; shaded circles, type IV; circles with x, type V. Triangles are centroids of each group. Samples 43 (7.6 per cent carbon) and 58 (3.8 per cent carbon) not shown, but these values were used in computing centroids.

The analytical expression for the relation shown in Figure 4 may conveniently be written as $d/d_0 = e^{-ap}$, where d refers to the diameter in millimeters, p is the percentage of organic carbon, d_0 and e are constants, and a is a coëfficient of carbon content, also constant. This expression defines carbon content as the independent variable, but it

[14] This follows from the fact that an exponential function plots as a straight line on semilogarithmic paper. The size scale at the top of Figure 4 is logarithmic.

[15] P. D. Trask and H. E. Hammar, "Preliminary Study of Source Beds in Late Mesozoic Rocks on West Side of Sacramento Valley, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), p. 1361.

is probably not appropriate to read a causal relationship into the equation. It seems likely that both carbon content and size are functions of the quietness of the water, inasmuch as the finer sediments and the organic matter are deposited under similar conditions.

RELATION OF SIZE AND CARBON CONTENT TO ORIGIN AND MIGRATION OF PETROLEUM

In his detailed study of the shoestring sands of Kansas, Bass[16] concluded that the linear sand bodies originated as offshore bars in an environment favorable to the rapid accumulation of organic matter. These bars served as reservoirs for oil which migrated from adjoining sediments, presumably within a mile or so laterally, and within a few feet vertically. The writers believe that the present study supports Bass' work by providing supplementary data on the processes involved in the migration and trapping of the oil.

During shifts in shore lines due to advancing or retreating seas, one may postulate that an environment similar to Barataria Bay may be buried beneath later deposits without any significant disturbances of the sediments already present. The result of such burial may be the superposition of a similar but laterally displaced environment above the present pattern. The net effect may be that muds may overlie sands in such a manner that any single well which penetrates the strata may show interbedded coarse and fine sediments. Adjacent wells may display irregularities due to lenticular beds, with the result that the essentially simple pattern of the present bay may be completely obscured. Nonetheless, if closely spaced wells tapped the environmental pattern in sufficient detail, the entire structure of the buried environment could be reconstructed in the laboratory.

Figure 2 shows not only that the sand occurs in a linear zone along the barrier beach, but also that fairly coarse sediments penetrate into the bay in a crude dendritic pattern. Thus there are direct connections between coarse and fine materials of the same age, with all shades of transition between. During subsequent burial, the finer sediments will be compacted much more than the coarser materials, with the result that oil will tend to migrate from the finer material through the dendritic arrangement of intermediate deposits, and finally accumulate in the coarse sands of the barrier. The dendritic channels thus serve as natural conduits for collecting the oil and directing it into the reservoir. As compaction continues, the linear sand bodies will

[16] N. W. Bass, "Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas," *Kansas Geol. Survey Bull. 23* (1936).

stand above the surrounding contemporary beds, and may well serve as reservoirs without the intervention of diastrophic adjustments.

By offering natural conduits for migration, it is not necessary to restrict the migration to a mile or less. It seems likely that such zones of intermediate material may penetrate for several miles into the environment, and tap a fairly large area. Likewise, oil may move from muds both above and below the barriers into the reservoir, and thus enhance the richness of the pool.

The environmental pattern of Barataria Bay suggests that the net effect of petroleum migration would be the accumulation of oil in the linear sand bodies, in the absence of any diastrophic controls that may modify the normal development of the barriers as traps. In effect this migration involves (1) movement from structural depressions to structural "highs," (2) movement from fine to coarse sediments, and (3) movement from regions of high carbon content to regions of low carbon content. Each of these factors plays a rôle in the process. It seems to the writers that these several factors may be isolated by means of maps, which may shed light on the broader problems of petroleum migration and accumulation. Structure contour maps afford data on the rôle of elevations and depressions; size contour maps[17] may indicate the rôle of increasing permeability; carbon contour maps show the regional variation in carbon content. Each of these maps represents a "field" as the term is used in physics. Each field plays a greater or lesser rôle in migration, by effecting some control on the most likely direction of movement. Thus one may visualize a complex environment of size, structure, carbon, and other gradients, and from the relations among them, it may be possible to evaluate the relative contribution of each. Such an approach resolves the complex problem into several elements, each of which may presumably be investigated quantitatively. Studies may be made of known petroliferous regions to reconstruct the migrational history of the oil, or they may be made on selected modern environments where the processes of deposition are still taking place.

[17] See Krumbein and Aberdeen, *op. cit.* (1936).

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TYPE SECTION OF BAINBRIDGE FORMATION OF SOUTHEASTERN MISSOURI[1]

JOHN R. BALL[2]
Evanston, Illinois

ABSTRACT

The type section of the Bainbridge formation of southeastern Missouri is about one mile south of Moccasin Springs. The Bainbridge includes some red, strongly mottled, argillaceous limestones; some poorly bedded, greenish gray earthy limestones; and a conspicuous unit of finely laminated dark brown shale in which *Cyrtograptus ulrichi* Ruedemann is the conspicuous fossil. The section is more than 100 feet thick, but its base is below water level and a railroad embankment is against the foot of the bluff. The formation has been traced by many geologists in discontinuous exposures from Ste. Genevieve County into Cape Girardeau County, Missouri. It has been observed, also, in Alexander County, Illinois, and has been reported from other localities within that state. Lithologically it seems to be identical with parts of the Henryhouse formation of Oklahoma, the Lafferty of Arkansas, and with certain beds in the Silurian of western Tennessee. More exact correlations with these formations possibly may be accomplished by further faunal studies.

Shumard,[3] in 1873, described and measured some of the Silurian strata exposed in the bluff of the Mississippi River in southeastern Missouri. From Shumard's references it seems probable that the exposures he studied include some which are near Moccasin Springs.

Ulrich,[4] in 1904, applied the formation name of Bainbridge to the strata extending along Bainbridge Creek about 3 miles south of Moccasin Springs. Essentially the entire thickness of the Niagaran strata crops out about one mile south of Moccasin Springs in the Mississippi River bluff. The exposure is in the head of a small box canyon in the SE. ¼, SE. ¼, NW. ¼ of Sec. 24, T. 32 N., R. 14 E., Fifth Principal Meridian and Baseline. This outcrop is the most extensive of several being developed along the bluff, so it may be regarded as the type section of the Bainbridge formation.[5] It is now thought to be about ½ mile south of the exposure measured by Shumard.[6]

Through a thickness of slightly more than 120 feet the strata are exposed in a vertical cliff. Some protruding ledges (Fig. 1) exist so that exact measurement in several places is difficult. This difficulty has been obviated to some extent by the substitution of measurements

[1] Manuscript received, February 3, 1939.

[2] Department of Geology and Geography, Northwestern University.

[3] B. F. Shumard, "Cape Girardeau County," *Reports of the Geological Survey of the State of Missouri*, 1855–1871, (1873) p. 262.

[4] E. R. Buckley and H. A. Buehler, "The Quarrying Industry of Missouri," *Report Missouri Bureau Geology and Mines*, Vol. II, 2nd Ser. (1904), p. 110, quoting letter from E. O. Ulrich.

[5] Josiah Bridge, personal communication.

[6] B. F. Shumard, *op. cit.*, and map following p. 273.

of identical strata cropping out about 200 feet south of the type section. Even with the attempted correction, however, several units in the section following (indicated by asterisks) are disposed of by close approximations of actual thicknesses.

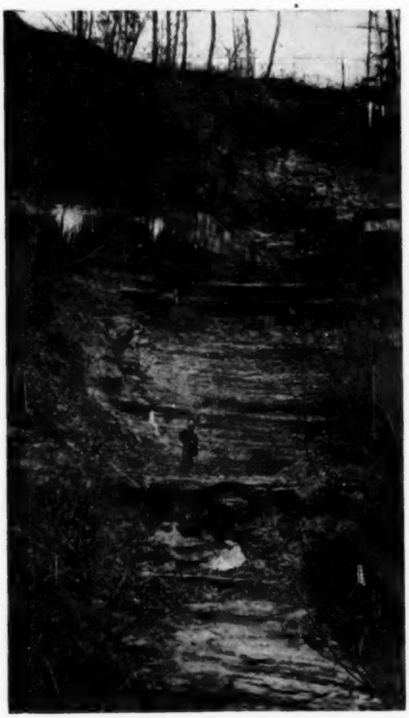

FIG. 1.—Type section of the Bainbridge formation, about one mile south of Moccasin Springs, Missouri. *Cyrtograptus* horizon rests on upper surface of prominently protruding ledge, second from uppermost ledge.

SECTION EXPOSED IN MISSISSIPPI RIVER BLUFF, TYPE SECTION OF BAINBRIDGE FORMATION, NW. ¼, SEC. 24, T. 32 N., R. 14 E.

Strata	Thickness Feet	Thickness Inches
15. Gray and greenish limestone, a zone of uncertain assignment at base, grading upwards into unquestioned Bailey limestone, with interbedded cherts, Helderbergian (not measured).		
14. Mottled limestone, gray, with reddish and purple banding, resistant, well bedded above, shaly near the base, with *Striatopora flexuosa* and *Bainbridgia typicalis* n. sp.	11	

13. Gray earthy limestone, stained with green, some purple mottling, bedding indistinct, occasional calcite vugs, marcasite nodules, invertebrate trails, *Cyrtograptus ulrichi* sparsely distributed in basal part, about	24*	
12. Dark brown to black shale, compact, well laminated, *Cyrtograptus ulrichi* Ruedemann abundant	5	
11. Gray to green limestone, earthy, massive, resistant, a few *Dalmanites*, pygidia, about	4–6*	
10. Dark red shaly limestone, locally somewhat crystalline and hard, shaly parting at base, highly fossiliferous	1	
9. Red and green limestone, coloring not uniform, weathering into nodular or sub-spheroidal aggregates, few fossils	2	
8. Light green limestone, poorly bedded, nodular, irregular fracture surfaces	1	4
7. Red, massive limestone, weathering into large sub-spheroidal aggregates, persistent unit across exposure	2	4
6. Greenish gray and red shaly limestone, coloring somewhat banded, bedding indistinct, massive towards top	16	6
5. Red flaggy limestone, mottling not conspicuous, somewhat resistant	11	
4. Mottled red limestone, the mottling a greenish gray, slightly shaly, somewhat resistant, conspicuous joints, nodular weathering aspects, sparsely fossiliferous near base, *Dalmanites* most common, standing in massive ledge across canyon	13	9
3. Mottled red limestone, greenish bands less prominent than the red, massive at base	5	
2. Covered interval, grade fill of St. Louis and San Francisco Railroad	24	
1. Dark red shaly limestone, some interbedded gray limestone, poorly bedded, prominent joints, trails of invertebrates, a few *Dalmanites*, exposed above river, December, 1938	4	

In descending order, units 14 to 11 of this section appear to correspond closely with strata recognized by Shumard, with some slight variations in thicknesses. However, Shumard[7] reported the greater number of fossils in the earthy limestone above the *Cyrtograptus* shale. As far as it has been possible to study the occurrence of fossils in this exposure, the greater number appear in stratum No. 10. The following list presents in part some of the species which have been noted:[8]

Enterolasma cf. *waynense* (Safford)
Orthis? sp.
Dalmanella, 2 sp.
Leptaena rhomboidalis (Wilckens) (Small individuals)
Camarotoechia sp.
Atrypina sp.
Atrypa reticularis (Linnaeus)
Delthyrus crispus simplex (Hall)
Nucleospira sp.
Merista tennesseensis Hall and Clarke
Bellerophon sp.
Eotomaria sp.
Cyclonema sp.
Strophostylus, 2 sp.
Diaphorostoma brownsportense Foerste
D. cf. *niagarense* (Hall)
Orthoceras, 2 sp.
Bumastus sp.
Proëtus sp.
Calymene sp.
Homalonotus sp.
Dalmanites, 2 sp.

Remaining beds in the section are not abundantly fossiliferous, although the green limestone above the fossiliferous bed, No. 11,

[7] *Op. cit.*, p. 262.

[8] Presented in part at Toronto meeting of the Paleontological Society, *Bull. Geol. Soc. America*, Vol. 42 (1931), p. 352.

yields a few fossils, a species of *Dalmanites* being the most common. The strata in which other fossils occur have been designated in the description of the section.

DISTRIBUTION OF BAINBRIDGE FORMATION IN SOUTHEASTERN MISSOURI AND IN SOUTHERN ILLINOIS

The sporadic surface occurrences of the Bainbridge in Ste. Genevieve County, due to the fault mosaic of that region, have been described by Weller.[9] Flint[10] has traced it through the southeastern part of Perry County and into Cape Girardeau County. Bridge[11] has mapped its distribution in the Jonesboro, Missouri-Illinois, Quadrangle.

Brief reconnaissance studies of its occurrence in southern Illinois have been made. It has been recognized in three outcrops near Thebes.[12] One exposure is under the bridge which crosses Orchard Creek in the SW. ¼, NW. ¼ of Sec. 21, T. 15 S., R. 3 W., about 1½ miles south of Thebes. Much of the exposure is covered by water. In December, 1938, the following section was visible.

SECTION EXPOSED UNDER BRIDGE ACROSS ORCHARD CREEK NEAR MOUTH OF ROCK SPRINGS HOLLOW

Strata	*Thickness* *Feet*	*Inches*
5. Alluvium, with "bronzed chert" pebbles, not measured		
4. Light grayish green shale, stained with manganese, in beds 4–8 inches thick, somewhat thin-bedded locally, but mostly massive, irregular fracture, fossils not observed, bridge abutment resting on this unit.	4	4
3. Green shale, slightly darker than above with weathered areas of limonitic brown, breaking into large, irregular plates, fossils not observed, a small exposure on upstream side of bridge.		7
2. Olive green limestone, somewhat massive locally, weathered patches of green and brown, upper surface nodular, with limonite nodules and with limonite healing the fissures, well jointed, fossiliferous, *Dalmanites* common, apparently gradational downward, about. . .	2	
1. Mottled limestone, prevalently green, but with red and purple mottling near top, becoming more uniformly red near water level, fairly well bedded, much fractured and nodular toward lower laminae, sparsely fossiliferous, *Lingula* sp., exposed, about.	2	

The strata have a slight westerly dip (Fig. 2), and on account of the prevalent green shaly material, and the occurrence of *Dalmanites*,

[9] Stuart Weller and Stuart St. Clair, "Geology of Ste. Genevieve County, Missouri," *Missouri Bureau of Geology and Mines*, Vol. XXII, 2nd Ser. (1928), pp. 126–30.

[10] R. F. Flint, "The Geology of Parts of Perry and Cape Girardeau Counties," *Univ. Chicago Ph.D. dissertation*, unpublished manuscript (1925), pp. 88–91.

[11] Josiah Bridge, *Missouri Geol. Survey* unpublished manuscript.

[12] The writer is indebted to H. S. McQueen for personal communications concerning Bainbridge outcrops. J. V. Howell kindly has supplied some of his field notes and has accompanied the writer in field studies. Lyle McManamy and Dan Stewart of the Missouri Geological Survey have directed the writer to the outcrops near Thebes.

are at the same horizons, possibly, as units 10 and 11 in the type section.

The other near-by exposures of the Bainbridge are in creek bottoms and are not in favorable position for measurements. Discontinuous exposures are near the farm buildings of Gerald Clutts in the NE. ¼ of Sec. 21, T. 15 S., R. 3 W. Near the base of this section a pink crystalline limestone is distributed in massive blocks along the creek bed. This limestone crops out above the typical cherty Brassfield in many

Fig. 2.—Bainbridge formation in Illinois, 1¼ miles south of Thebes. Abutment of bridge crossing Orchard Creek shown in upper right corner.

places. Its presence in this exposure suggests that the Brassfield may be in the covered interval between it and the Girardeau limestone in Rock Springs Hollow.

One other exposure of the Bainbridge formation in this vicinity is in "Powder Mill Hollow" in the SE. ¼ of Sec. 28, T. 15 S., R. 3 W., southwest of the Santa Fe Hills. It is a short distance east of the railroad tracks in the more northerly of the gullies in the region of the old powder mill. Here, massive blocks of Girardeau and Bainbridge limestones stretch across the gully in a disordered mass (Fig. 3). The displacement of the blocks seems more suggestive of faulting than of normal slump, but the outcrop awaits more detailed study.

The measured section in the bed of Orchard Creek, 1½ miles north of "Powder Mill Hollow" also is suggestive of faulting. In the vicinity of the type section, in Missouri, the Bainbridge horizons, thought to be exposed also in the bed of Orchard Creek, are at least 100 feet, stratigraphically, above the Girardeau limestone. The Girardeau

limestone forms the cascades in Rock Springs Hollow. Downstream from the cascades and at the level of the Mississippi River the slight section of the Bainbridge is exposed. There does not seem to be sufficient dip in the Alexandrian rocks to bring about this relationship. The stratigraphic and structural evidence in the two Bainbridge outcrops suggests a fault mosaic of unknown pattern in this part of Alexander County.

FIG. 3.—Massive blocks of Girardeau and Bainbridge limestones in small valley, 3 miles south of Thebes, Illinois.

Worthen,[13] in 1868, recognized the probable thickness of the Silurian rocks in Alexander County and mentioned outcrops east of Thebes where the rocks display "mottled" and "reddish brown" characteristics. These features suggest Bainbridge lithology but possible occurrences farther east in this locality have not been sought out.

Savage,[14] in his detailed and constructive studies of the Silurian system in Illinois, separated the Alexandrian series from the sequence recognized by Worthen. Savage and Lamar also have noted the Bainbridge in southeastern Union County, Illinois, in localities east of Reynoldsville.[15]

Lithologically the Bainbridge of Illinois is identical with that for-

[13] A. H. Worthen, "Geology of Alexander County," *Illinois Geological Survey*, Vol. III (1868), pp. 25–26.

[14] T. E. Savage, "Stratigraphy and Paleontology of the Alexandrian Series in Illinois and Missouri," *Illinois State Geol. Survey Bull. 23* (1917), pp. 67–82.

[15] J. Marvin Weller, personal communication.

mation in southeastern Missouri, with the Henryhouse in Oklahoma, probably with the Lafferty in Arkansas, and with some parts of the Silurian strata of western Tennessee. It is hoped that paleontologic studies now in progress will suggest further correlations between members of the Niagaran series in these localities. In Ste. Genevieve County, Missouri, where the fauna of the Bainbridge has been studied in greater detail,[16] there is a suggestive similarity between the faunules of the Bainbridge formation and the Brownsport formation of western Tennessee. In Ste. Genevieve County a white crystalline limestone contains the species which are in common with the Brownsport fauna. This limestone occurs near the base of the Bainbridge. On the other hand, the Beech River and Bob members of the Brownsport where the Bainbridge fossils occur are relatively high in the Tennessee Silurian section. This suggests that in Missouri few Silurian formations below the Brownsport horizons are represented. Dunn,[17] however, on the evidence of the micro-fauna has suggested that the Osgood formation possibly is represented in the Missouri Bainbridge.

The writer is deeply indebted to Carey Croneis of the University of Chicago for reading the manuscript and for most helpful criticism.

[16] R. F. Flint and John R. Ball, "Revision of the Silurian in Southeastern Missouri," *Jour. Geology*, Vol. 34 (1926), pp. 248–56.

[17] Paul Dunn, personal communication.

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GEOLOGICAL NOTES

NEW DEVELOPMENT IN ORANGE FIELD, ORANGE COUNTY, TEXAS[1]

R. L. BECKELHYMER[2]
Houston, Texas

The Orange field was discovered in 1913, and reached its peak of production in 1922. To January, 1938, approximately 450 wells had been drilled. Of these, approximately 325 were producers—the others dry. The 325 producing wells had a cumulative production through 1937 of 32,296,366 barrels—the greater part of this oil coming from Miocene sands. After reaching its peak, production gradually declined until 1935, at which time the field was practically dormant insofar as drilling operations were concerned. The early history and development of this field has been ably described by Deussen and Andrau,[3] and need not be further discussed here.

Although 450 wells have been drilled, logs were so poorly kept that the field is almost as much a structural puzzle to-day as it was at the time of its discovery.

In May, 1935, Dick Schwab began drilling his Banker and Ruten No. 1, which was finally abandoned at 7,265 feet. This well inaugurated a new sporadic drilling program that resulted in the discovery of a new producing zone. This well was the first in the field in which a Schlumberger test was made; the first to furnish a good set of paleontological points, and the first to provide really dependable stratigraphic information about this field.

Schwab's well was followed in turn by four others, drilled in 1936, ranging in depth from 6,163 feet to 7,867 feet. All of these were dry and abandoned, but they did provide additional reliable information and showed the presence of deeper sands, giving operators an incentive beyond the shallow zones.

In December, 1936, J. R. Turnbull (later acquired by the Union Producing Company) completed the Lutcher-Moore No. 1 as a gas-distillate well in the *Heterostegina* zone through perforations from

[1] Manuscript received, March 4, 1939.

[2] Union Producing Company.

[3] Alexander Deussen and E. W. K. Andrau, "Orange, Texas, Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 5 (May, 1936), pp. 531–59.

5,580 to 5,600 feet, the well having been plugged back from 7,094 feet.

Development and exploration work again lagged until November, 1937, when Ryan and Tillery brought in the Allie Chesson No. 1, located on the southwest flank of the dome, at a total depth of 5,946 feet. This well is producing 35° gravity oil from a sand approximately 200 feet below the *Marginulina* zone. It was the discovery well in a new producing zone in the Orange field.

On April 14, 1938, five months after Ryan and Tillery's Chesson No. 1 was completed, the Union Producing Company completed their Lutcher-Moore No. 2 in the same zone. It was the tenth well completed in the newly discovered sand, and came in through perforations from 5,960 to 5,975 feet, with a potential of 587 barrels on a ¼-inch choke, after having been plugged back from a total depth of 7,315 feet. This well has the distinction of being the first well to reach salt in the Orange field. Salt was topped at 7,125 feet and was continuous to the total depth.

Through December, 1938, the Gulf Refining Company, the Shell Petroleum Corporation, the Union Producing Company, Redbank, C. L. Brown, and others had completed 22 wells in the new zone. Their cumulative production through December, 1938, was 279,428 barrels.

Consistently good core records with a sand description are not available, but the sand is generally described as being light gray, medium- to fine-grained, soft to firm, and porous. The Union Producing Company's Lutcher-Moore No. 2 is the only well on which a laboratory analysis is available. This analysis shows 35.9 per cent porosity, and is for one core only. On the southwest flank of the dome, where the discovery well is located, there is a probable maximum sand thickness of 12 feet, and in some places this is very shaly. The sand condition is apparently a little better on the northern part of the dome. Here, the wells have 15–20 feet of sand and it is less shaly.

A generalized section from the base of the heavy sand above the *Discorbis* zone to the producing sand is as follows: base of sand to *Heterostegina* zone, 350 feet of shale with sand streaks; *Heterostegina* zone to the producing sand, 300 feet of shale and sandy shale; a total thickness of approximately 650 or 700 feet from the base of the heavy sand to the producing zone.

Structural interpretations at this time are very unsatisfactory. A north-south fault of major size has been recognized, but until more wells have been drilled and more information is available, details of the structure are unknown.

EVIDENCE OF EROSION OF SALT STOCK IN GULF COAST SALT PLUG IN LATE OLIGOCENE[1]

MARCUS A. HANNA[2]
Houston, Texas

From time to time statements and cross sections have been made which indicated truncation by erosion of cap rock and salt stocks in Gulf Coast salt domes. These deductions have been based on information of two types: first, the absence of beds on the particular salt structures, and second, theoretical consideration of sequence of the several types of cap rock.

It has been stated, "Erosion has been effective in stripping some structures of the accumulation of less soluble residues. The section through the Hawkinsville dome, Matagorda County, Texas (Fig. 12), illustrates the effectiveness of such erosion."[3] Figure 1[4] is a diagrammatic section but is very close in relationship to a section through the Orchard dome, Fort Bend County, Texas. Figure 2[5] is a diagrammatic section but is very similar to a section through the Hawkinsville dome, Matagorda County, Texas. Both of these domes were stripped, as judged by the sequence of beds, at approximately the beginning of Lissie time (Pleistocene).[6] Such a deduction is due to the presence of Lissie beds in contact with the dome material, that is, gypsum or anhydrite and limestone.

The theoretical consideration of sequence of the several types of cap rock is well illustrated in Figures 1 and 2. The presence of a limestone cap-rock section on the periphery of the dome and extending to the top of the salt structure but absent over the center of the dome theoretically is indicative of truncation by erosion. In such domes it is believed that the limestone cap rock at one time extended over the dome but has been eroded away.

When salt breaches and invades overlying beds, fragments or blocks of the adjacent beds are carried forward either in the salt or along the salt-sediment contact as a breccia or gouge. Because of this, blocks of different types of material and of different ages may be found in contact, either within the

[1] Manuscript received, March 6, 1939. Published with permission of the Gulf Oil Corporation and the Pure Oil Company.

[2] Gulf Oil Corporation.

[3] Marcus A. Hanna, "Geology of the Gulf Coast Salt Domes," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 665.

[4] *Ibid.*, p. 640, Fig. 5, No. 4.

[5] *Ibid.*, p. 641, Fig. 6, No. 8.

[6] F. B. Plummer, "Cenozoic Systems in Texas," *Univ. of Texas. Bull. 3232*, Pt. 3 (1932), p. 530.

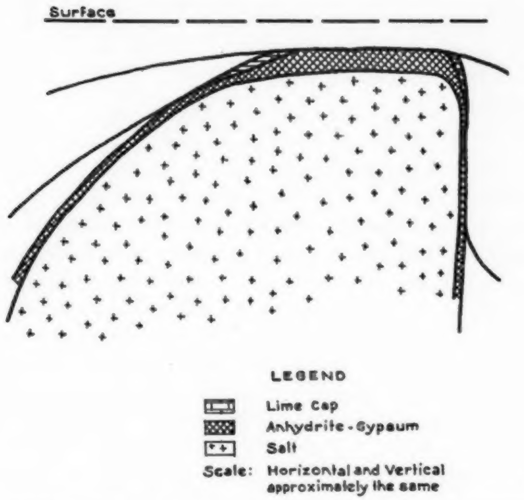

FIG. 1.—Diagrammatic section similar to section through Orchard dome, Fort Bend County, Texas.

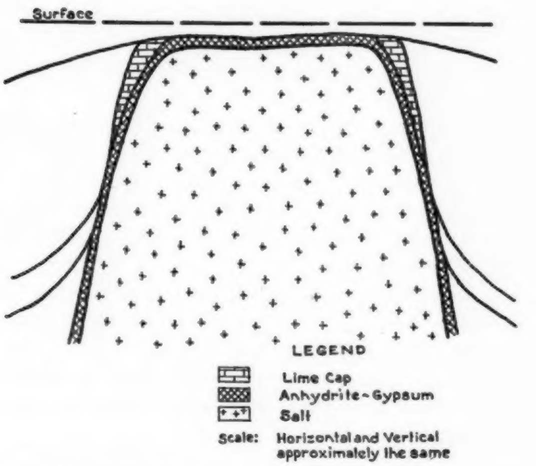

FIG. 2.—Diagrammatic section similar to section through Hawkinsville dome, Matagorda County, Texas.

breccia itself or with the formations adjacent to the salt core. If the salt reaches the surface and flows out as a glacier, large quantities of this detritus may accumulate at the surface. Harrison's[7] description of the Hormus series of southern Persia well illustrates this condition.[8]

Until recently the writer had observed no material which could be considered definitely as detritus from the erosion of cap rock or salt plug. Recently in the examination of samples from the Pure Oil Company's W. W. Smith No. 1, Peach Point, about 6 miles southeast of Brazoria, Brazoria County, Texas, crystals of anhydrite were found in cuttings from a depth of 7,780–7,800 feet and in the deeper cuttings. These anhydrite crystals are typical of the random anhydrite crystals which make up 5–10 per cent of the salt stock mass. They indicate erosion of the salt itself. They are slightly worn. No clusters of crystals such as might result from anhydrite cap-rock erosion were found. There is no evidence that the well penetrated the gouge zone between a salt dome and the surrounding sediments. The summation of evidence points to deposition of these anhydrite crystals as detrital material. No statement can be made regarding the distance the anhydrite crystals were transported.

Here, then, seems to be definite evidence of the erosion of a salt stock at the time the beds at 7,780–7,800 feet were being deposited, as well as possibly lower beds, although the anhydrite crystals in the deeper cuttings could be contamination from beds as high as 7,780–7,800 feet. The first *Heterostegina* fragments noted in the well were from 8,100–8,120 feet, which would date the age of this erosion as late Oligocene.[9]

In some recently drilled wells in this general area certain of the Oligocene fossils commonly used as horizon markers have been found above their characteristic horizons. It now seems quite possible that these fossils may have been reworked from an eroding salt dome. In one or two other areas similar reworking appears to have taken place in late Oligocene time.

It is not possible to state which dome or domes in the Peach Point region may have been eroded in late Oligocene time. Stratton Ridge, Bryan Heights, Allen, and Clemens in Brazoria County and Hawkinsville in Matagorda County are sufficiently close. In addition a more deeply buried dome than those mentioned (but which is as yet unknown) is possible.

[7] John Vernon Harrison, "The Geology of Some Salt Plugs in Laristan (Southern Persia)," *Quart. Jour. Geol. Soc.*, Vol. 86, Pt. 4, No. 344 (1930), pp. 473–75.

[8] Marcus A. Hanna, *op. cit.*, pp. 644, 646.

[9] F. B. Plummer, *op. cit.*, p. 530.

In conclusion, since truncation by erosion has occurred on Gulf Coast salt domes in Pleistocene and late Oligocene, it is not unlikely that truncation occurred at other times. Whether such domes were rejuvenated is not known. Exhaustion of the salt at the source of such domes or other causes may have precluded rejuvenation. Little can be stated with certainty about the deeper buried domes themselves, whether eroded or not eroded. Only additional information will complete the picture.

GEOLOGIC ASPECTS OF HEAVING SHALE IN TEXAS COASTAL PLAIN

CORRECTION

The writer regrets that errors in drafting occurred on the map published in his article entitled "Geologic Aspects of Heaving Shale in Texas Coastal Plain," which appeared in the February issue of the *Bulletin* (Vol. 23, No. 2).

The following corrections should be made: Pedras Lumbre should read Piedra Lumbre; Ezell should read Ezzell; Loma Novita should read Loma Novia; Callihan should read Calliham; Sarnoca should read Sarnosa; Amargosa should read Armagosa; Charamusa should read Charamousca; Telfener should read Telferner; Mestinas should read Las Mestenas; Henne-Winch-Ferris should read Henne-Winch-Farris; Alta Vista should read Loma Alta; and the Adams well in Jim Wells County should be slightly northwest of the point of junction between Jim Wells, Kleberg, and Nueces counties.

The writer would appreciate the indulgence of the members of the American Association of Petroleum Geologists in making these corrections.

J. M. Frost III

Austin, Texas
March, 1939

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

AMBER AND ITS SIGNIFICANCE, BY KARL ANDRÉE

REVIEW BY R. D. REED[1]
Los Angeles, California

Der Bernstein und seine Bedeutung in Natur- und Geisteswissenschaften, Kunst und Kunstgewerbe, Technik, Industrie und Handel, nebst einem kurzen Führer durch die Bernsteinsammlung der Albertus Universität, Königsberg (Pr.), (Amber and Its Significance in the Arts and Sciences, the Handicrafts, Engineering, Industry, and Commerce; with a Short Guide to the Amber Collection of Albertus University, Königsberg, Prussia), by Karl Andrée. 219 pp., 51 figs. Gräfe und Unzer, Königsberg (1937). Price: paper, RM2.50; cloth, RM3.50; 25 per cent discount is allowed on orders outside of Germany.

More than 300 miles northeast by east from Berlin lies Königsberg in the Pregal River valley south of the Peninsula of Samland. Four or five miles west of the city the river empties into a lagoon that stretches away to the southwest for perhaps 50 miles. This lagoon, which bears the curious name of "Frisches Haff" is separated from the semi-circular Danzig Gulf by a long sandspit, the Frische Nehrung. Danzig and the mouth of the Vistula are beyond the attached southwest end of the sandspit. North of the Haff lies Samland, facing the Baltic and bearing several towns and villages. Palmnicken at its western end is one that should perhaps be noted. Northeast of Samland is another Haff, the "Kurisches," separated from the Baltic by the equally "Kurische" Nehrung or sandspit, near the north end of which lies the city of Memel. Half-way between Danzig and Memel, Königsberg seems likely to make the headlines at any time. If so, no matter how stirring the events to be recorded, they will hardly be more so than many others of its long history, which goes back to the foundation of a castle on its site by the Teutonic knights in 1255. The King whose "Berg" it originally was is said to have been King of Bohemia.

To non-residents of East Prussia, Königsberg is perhaps best known as the one-time home of Immanuel Kant, the eighteenth century professor who invented one variety of the nebular hypothesis and a system of philosophy. Geological non-residents may also recall that Königsberg is the center of the amber trade. This last-mentioned claim to fame is the one that makes the geological history of its neighborhood worthy of some consideration at present.

In the Upper Eocene and Lower Oligocene the Samland area lay in a shallow sea-arm, stretching eastward into Russia and separating the ancient and hilly Scandinavian upland on the north from the Polish plain on the south. The southern slope of the Scandinavian upland was drained into the east Prussian sea by streams that meandered through a remarkable subtropical

[1] Chief geologist, The Texas Company (California). Manuscript received, March 11, 1939.

forest very much like that which now covers parts of southern Florida. Among its many kinds of trees, this forest had several varieties of pine and fir, which in certain areas must have grown in fairly pure stands. The pines, in particular, sometimes grouped as *Pinus succinifera*, were great producers of resin, large or small masses of which were exuded by them at the slightest provocation. Some of the masses fell upon the ground and engulfed bits of moss, dirt, leaves or even small animals; others remained upon the trees until the trees fell. During the earlier part of their existence, these masses were so sticky as to gather unto themselves pollen grains, leaves, petals, insects and other small flying or drifting objects that touched them. Upon solidifying later on, masses of resin became the most perfect preservative ever developed for such delicate objects as insect wings and flower parts.

Being resistant to weathering, the amber masses outlasted the forest from which they were produced and became imbedded in the carbonaceous glauconitic sand and clay strata that accumulated in the East Prussian sea during Upper Eocene and Lower Oligocene time. Many of them have even outlasted several more recent re-workings, first into Middle Tertiary lignitic strata and later into Pleistocene or Recent deposits of different kinds. In considerable quantities they are still washed up on the East Prussian beaches after storms.

When the ancient hunters followed the retreating ice sheets into Denmark and north Germany after the Ice Age they were immediately attracted by these curious masses of soft, yellow material that burned with a good flame, were in many cases transparent, became electrified upon rubbing, and could easily be cut with a flint knife into any shape that one's superstition or artistic sense suggested. Collections of amber were made during Stone Age time, most of those we have found being of the later, or Neolithic period. By Bronze Age times the material was traded over most of Europe, great quantities going to the cities of the Mediterranean where it attracted the attention of Homer and many of the classic writers who followed him. Tacitus and Pliny tell long stories about it. So much of it was brought overland to Aquileia, a city at the head of the Adriatic, as to give rise to a fairly common belief that the amber-producing country was somewhere in the outskirts of that city. Even now the museum at Aquileia is said to have one of the best of all collections of worked amber, better even than that of Albertus University in Königsberg itself.

To nearly all ancient men and to many modern men it has been obvious that a substance with as many remarkable qualities as amber must be good for most or possibly all diseases; and efficacious, perhaps, in preventing evils of other kinds. The practical Neolithic people probably carved it into likenesses of enemies or food animals with the idea of keeping them, along with their amber likenesses, under good control. Later men carved it into amulets, beads, rosaries, and other useful objects. In the sixteenth century the Reformation is said to have caused a temporary slump in the amber business by creating a group of non-rosary-using Lutherans in all the country adjoining Samland. As a partial compensation, Albertus I, duke of Prussia, founded the Albertus University in 1544, and that place of Lutheran learning has since grown into a great center for the preservation and study of amber and its lore. The present curator of the amber collection of the Albertus Museum is Professor Karl Andrée, head of the department of geology in the University.

In Professor Andrée's little book, which serves as the excuse for the present discourse, may be found in simple language a fascinating account of am-

ber, its history, its relation to art and archeology, the many names by which it has been known and their meanings, the geological and paleobiological results of its study, and other details too numerous even for mention here. Amber fossils seem to have attracted the attention of amber collectors and others from very early times. It was Homer, I believe, who first made a statement about them that has been preserved. The Roman poet Martial wrote three epigrams about fossils in the amber; one about an ant, one about a bee, and the third about a "viper," the exact identity of which has been the subject of many learned discussions. More recent paleontological studies have been numerous, but others are still greatly needed. The flora and fauna are so rich as to be almost unbelievable. Try to imagine a collection of insects in which at least 452 genera of beetles are found, though more than half of the fossils belong to the Diptera, and many other groups are well represented. The flora includes not less than 57 genera and 98 species of Dicotyledons, 15 of the species being oaks; there are also date palms and other palms, cypresses, yews, junipers, and cycads, as well as mosses, ferns, and liverworts. All these in a forest that is best thought of as a pine forest. Flowers are well represented, of course, as they rarely are among plant fossils from other localities. Thus, in spite of the fact that many kinds of fossils normally found in Early Tertiary rocks occur rarely or not at all in the amber beds, we have here an almost unparalleled opportunity to learn intimate paleobiologic details about the life of the amber forest. A great deal has been done to promote this knowledge and much more needs to be done. Professor Andrée's work and that of his collaborators have contributed much toward the knowledge now available, and his little book furnishes an excellent means of spreading this knowledge among a wider public.

In spite of the fact that amber is the hydrocarbon of greatest historic and literary importance and that its economic significance is still considerable, its relations with petroleum and petroleum geology are not very close. The word, in fact, is not even listed in the *Comprehensive Index* of Association publications.[2] Though we may be told prehistoric men used amber to light fires with, or that in medieval churches it sometimes served as incense; or that, like petroleum, amber has passed through a long pharmaceutical career from the time when it was good for every ailment—see Pliny's *Natural History*—to the time when it can cure only a few mild diseases; the fact remains, nevertheless, that amber interests chiefly gem collectors and paint-makers; oil, chiefly motorists, business men, and geologists. My reason for writing a review of Professor Andrée's book is thus not any desire to expand the limits of our Association activities so as to include amber. I wish merely to call attention to an interesting book that deals with many phases of general and historical geology, and to ask why more and larger deposits of amber have not been found in countries distant from the Baltic Sea.

It is true, of course, as Professor Andrée indicates, that commercial deposits of amber have been found in several other localities, as in Roumania, Sicily, and Upper Burma; and that non-commercial deposits are widespread. Even in the United States amber was noted by Bartram before the Revolutionary War, and in the *American Journal of Science* for 1821 Dr. Troost described an occurrence from the Atlantic Coastal Plain. Many other deposits

[2] Daisy W. Heath, *Comprehensive Index of the Publications of The American Association of Petroleum Geologists, 1917–1936* (1937). 382 pp.

have been found since. In Mexico the Aztecs are said to have imported great quantities of excellent amber for use in making ornaments. In much later times, travelers in southern Mexico are said to have purchased large pieces of good amber from Indians who live in a district where the substance is so common that it is used for starting fires. In California, Frank B. Tolman found some pieces of Eocene amber in the Simi Valley a few years ago and has since collected others from Eocene rocks penetrated in deep wells near Coalinga. Why have not more and better finds of amber been made in California and elsewhere, particularly on the Gulf Coast? After all, there is a vast extent of Eocene marine and non-marine strata exposed in these areas, including the "Lignitic" Eocene of Texas and the "Auriferous" Eocene of California. These formations have yielded many plant fossils but no amber. Was the amber pine (*Pinus succinifera*) absent from the forests that produced them, or have the geologists who examined the strata been negligent in watching out for amber?

Anyone who reads Professor Andrée's little book will agree that the discovery of another large deposit of amber would constitute a great contribution to historical geology. Only try to imagine what we might learn from the fossils in the south Mexican amber, if the stories that have come out about that deposit could be verified and the locality studied in detail; or what we might add to our knowledge of the Eocene floras and faunas of Texas and California if we could find a few thousand well preserved fossil insects and flowers in amber fragments associated with the fossil leaves and shells that we now have. My best reason, perhaps, for reviewing Professor Andrée's book at such length is my hope that the review may assist the book in making geologists amber-conscious and thus leading to the discovery of other deposits of fossil-bearing amber.

GEOLOGY OF THE RHENISH-WESTFALIAN COAL DISTRICT, BY P. KUKUK

REVIEW BY WALTER KAUENHOWEN[1]
Hamburg, Germany

Geologie des niederrheinisch-westfälischen Steinkohlengebietes (Geology of the Rhenish-Westfalian Coal District), by P. Kukuk. 706 pp., 734 figs. Cloth. Approx. 7.5×11 inches. With a separate folder containing 14 plates. Julius Springer, Berlin (1938). Price: RM 66; 25 per cent discount is allowed on orders outside of Germany.

This book gives more than just a modern, detailed description of the geology of one of the largest coal-mining areas of the world. It covers in 23 chapters on more than 700 pages practically any phase of the geology of this district and its environs, namely, stratigraphy, paleontology, structure, mechanics of structural movements, surface and subsurface geology, sedimentary and coal petrology, paleogeography, hydrology, economic geology, *et cetera*. The book deserves general interest because it represents the most up-to-date symposium on what the author and other geologists have seen in an area, which through more than 800 mining shafts, galleries, underground workings, and bore holes became one of the geologically best known parts of

[1] Manuscript received, February 25, 1939.

the world. This fact makes the book valuable also to the oil geologist who is interested in the more general topics of his science.

Written and printed in a very readable way, the book is splendidly illustrated by more than 740 photographs, sketches, and diagrams. One of its main values consists in the 14 large plates, namely, 2 maps in colors (23×19 inches) showing areal and structural geology of the Westfalian basin, scale 1:350,000; a map showing subsurface and structural geology of the coal district (in colors), 1:60,000; 2 plates (in colors) with cross sections through the basin and its coal area; a contour map of the Paleozoic floor, 1:150,000; 3 plates showing areal geology and facies distribution of the Cretaceous cover rocks; 3 maps showing occurrences of economically important mineral deposits (ores, rocks, asphalt, natural gas, brines) within the Westfalian basin and its environs.

On pp. 564–73 the author describes the occurrences of natural gas, oil, oil shale, mineral wax, and asphalt found within the coal-bearing section of the basin and within its Cretaceous cover. According to the author the original source of these hydrocarbons is not certain, but he thinks it possible that they may be derived from Paleozoic (Devonian?, Mississippian?) rocks deposited within the foredeep of the Variscan mountain chains similar to conditions in Pennsylvania.

The last chapter contains a complete bibliography of several hundred numbers.

The book forms an important standard publication and reference work indispensable for any geologist interested in the problems dealt with.

THE EXAMINATION OF FRAGMENTAL ROCKS, BY FREDERICK G. TICKELL

REVIEW BY R. DANA RUSSELL[1]
Baton Rouge, Louisiana

The Examination of Fragmental Rocks, Revised Edition, by Frederick G. Tickell. x plus 154 pp., 54 figs., 20 tables. 7×10 inches. Cloth. Stanford University Press, Palo Alto, California (1939). Price, $4.00.

This revised edition of Professor Tickell's book has the same good qualities noted by a reviewer of the first edition: it "is clearly written, well illustrated, and substantially and attractively bound." Unfortunately, it also has most of the bad qualities, as the section on porosity and permeability (Chapter III) is the only one extensively revised. This chapter has been rewritten and increased to 24 pages, more than double its original length. Though the reviewer is not so familar with the techniques of porosity and permeability determinations, this section appears to be an excellent and up-to-date treatment.

Chapter I is a page and a half introduction. Chapter II (23 pages) is titled "Size Analysis," but includes notes on "degree of rounding," representation of size distribution (mechanical analyses), and on thin-section preparation. Very little change has been made in these chapters from the original edition. The method recommended for analysis of fine-grained sediments is

[1] Louisiana State University. Manuscript received, February 27, 1939.

that of undisturbed settling in test tubes, one which was obsolete when the first edition appeared (1931). No mention is made of the hydrometer or pipette methods. "Degree of rounding" is determined by a modification of the Cox method, in which shape, not roundness, is determined. Wadell's extensive work on shape and roundness is not noted, nor are any of his papers included in the bibliography. The methods recommended for determining the amount of skew and kurtosis of frequency curves are different from those usually employed by students of sediments.

Chapter IV, "Preparation of Specimens" (13 pages), is also essentially unchanged from the first edition, with no reference to modern methods of disaggregation and dispersion, though considerable space is devoted to little-used means of mineral separation, such as electrostatic and dielectric methods.

No important changes are evident in Chapter V, "Identification of Minerals" (43 pages), or Chapter VI, "Description of Minerals Found in Sedimentary Rocks" (30 pages plus determinative tables). Chapter V attempts to present optical methods of identification and, according to the author, "does not presuppose a knowledge of optical mineralogy." In the reviewer's opinion it falls short of its objective, as the treatment is so brief that one unacquainted with crystallography and optics will find it confusing. There are also erroneous statements, as: "The latter [maximum extinction angle] will be given only when the grain is lying on a cleavage face parallel to the optic plane." This is stated as a general law, whereas it is applicable only to monoclinic minerals in which the optic normal coincides with crystallographic *b*. The description of minerals lists only one value for each index and one value for the birefringence, no allowance being made for variations in members of isomorphous groups. In fact, no mention of such variations is made. Optic orientation is not given in the descriptions, but is shown for 18 of the biaxial minerals in "orientation-cleavage diagrams" which should be very useful.

Many of the typographical and other errors which marred the first edition have been corrected, though a few new ones were made during revision. The bibliography has been increased from 105 to 137 titles.

The first edition of this book undoubtedly fulfilled a useful purpose in assembling a number of methods commonly used in the laboratory study of fragmental rocks. With the exception of the section on porosity and permeability, however, the revised edition ignores the great improvements made in laboratory methods in the 8 years which have elapsed since the first edition appeared. Those not acquainted with the first edition will find some valuable suggestions in the book, but the reviewer feels that the disregard of modern techniques and other deficiencies limit its usefulness as a general laboratory manual.

RECENT PUBLICATIONS

ALABAMA, MISSISSIPPI, LOUISIANA

*Marine Pleistocene of the Gulf Coastal Plain: Alabama, Mississippi, and Louisiana," by Horace G. Richards. *Bull. Geol. Soc. America*, Vol. 50, No. 2 (New York, February 1, 1939), pp. 297–316; 3 pls., 4 tables.

CALIFORNIA

*"The Oil and Gas Fields of Kern County," by Paul J. Howard. *Oil World*, Vol. 32, No. 3 (Los Angeles, February, 1939), pp. 8–19; 1 table, 1 map.

*"Geology and Economic Significance of California's 1935–1938 Oil Discoveries," by William W. Porter II. *World Petroleum*, Vol. 10, No. 2 (New York, February, 1939), pp. 43–59, illustrated.

CANADA

*"Spectacular Gain in Alberta Production Despite Drastic Proration Rules," by J. L. Irwin. *Oil and Gas Jour.*, Vol. 37, No. 43 (Tulsa, March 9, 1939), pp. 74–76; 2 maps.

EGYPT

*"The Petroleum Deposits of Egypt," by M. Stchepinsky. *Annales Combustibles Liquides*, No. 5 (Paris, September–October, 1938), pp. 823–74; 1 map. In French.

GENERAL

**Bull. Geol. Soc. America*, Vol. 50, No. 3 (New York, March 1, 1939). Issue of semi-centennial presidential addresses and anniversary-day addresses. 147 pp. Contains the following.

"The Hot Springs Problem," by Arthur L. Day. Pp. 317–36.

"Review of Recent Progress in Reptilian Paleontology," by C. W. Gilmore. Pp. 337–48.

"The Rise of Physiography," by N. M. Fenneman. Pp. 349–60.

"The Problem of Petroleum," by F. G. Clapp. Pp. 361–74.

"Vertebrate Paleontology since 1888," by W. B. Scott. Pp. 375–86.

"Regional Departures from Ideal Isostasy," by R. A. Daly. Pp. 387–420; 12 figs.

"Deformation of the Earth's Crust," by W. H. Bucher. Pp. 421–32.

"The Rôle of Minerals in the Present International Situation," by C. K. Leith. Pp. 433–42.

"Contribution of Geology to Shaping of Ideas on the Meaning of History," by J. C. Merriam. Pp. 443–48.

"Ice Ages in the Geological Column," by A.P. Coleman. Pp. 449–52.

"Pleistocene History and Early Man in America," by G. F. Kay. Pp. 453–64; 2 figs.

*"Development and Production Problems in High-Pressure Distillate Pools," by E. V. Foran. *Petroleum Technology*, Vol. 2, No. 1 (New York, February, 1939). *Amer. Inst. Min. Met. Eng. Tech. Pub. 1023.* 9 pp.; 1 table.

*"Core Analysis," by Howard C. Pyle and John E. Sherborne. *Ibid., Tech. Pub. 1024.* 28 pp., 22 fig.

*"Effect of Pressure Reduction upon Core Saturation," by H. G. Botset and M. Muskat. *Ibid., Tech. Pub. 1025.* 12 pp., 6 figs.

*"Surface Chemistry of Clays and Shales," by Allen D. Garrison. *Ibid., Tech. Pub. 1027.* 14 pp., 3 figs., 1 table.

*"A Design for More Effective Proration," by Joseph E. Pogue. *Ibid., Tech. Pub. 1028.* 9 pp. Also in *Oil and Gas Jour.*, Vol. 37, No. 40 (Tulsa, February 16, 1939), pp. 29–30, 32.

*"Petroleum and Bitumen in Antiquity," by R. J. Forbes. *Jour. Inst. of Petroleum*, Vol. 25, No. 183 (London, January, 1939), pp. 19–23.

Fundamentals of the Petroleum Industry, by Dorsey Hager. 5th ed. 466 pp., 204 illus. 5.5×7.5 inches. Cloth. McGraw-Hill Book Company, 330 West 42nd Street, New York (1939). Price, $3.50.

**A Selected List of Periodicals, Serials, and Books Dealing with Petroleum and Allied Subjects and Where This Material May Be Found in Some Oklahoma, Texas, and Louisiana Libraries, together with a Group of Subject Bibliographies on the Petroleum Industry Obtained from the Technical Department of the Tulsa Public Library*. Compiled and collected by Clarence P. Dunbar and Lucille M. Dunbar. Published by the Louisiana Dept. of Conservation, New Court Bldg., New Orleans (1939). 217 pp., mimeographed, 8.5×14 inches. Paper cover.

*"Some Problems of the Middle Mississippi River Region during Pleistocene Time," by Percival Robertson. *Trans. Acad. Science Saint Louis*, Vol. 29, No. 6 (St. Louis, Missouri, May, 1938), pp. 169–240; 8 tables, 21 figs.

The Birth and Development of the Geological Sciences, by Frank Dawson Adams. 506 pp., 79 illus., 15 pls. 7×10 inches. The Williams and Wilkins Company, Baltimore, Maryland (1939).

GERMANY

Die Salzlagerstätten Deutschlands (The Salt Deposits of Germany), by Ernst Fulda. 140 pp., 52 figs. Gebrüder Borntraeger, Berlin (1939). Cloth. Price, RM 4.80 (25 per cent less, on orders outside Germany).

*"Über Bitumina im Rheinisch-Westfälischen Karbon" (Bitumen in the Rhenish-Westfalian Carboniferous), by Kurt Fiege. *Kali, Verwandte Salze und Erdöl* (Wilhelm Knapp, Halle, Saale), Vol. 33, No. 1 (January 1, 1939), pp. 1–3, Figs. 1–4; No. 2 (January 15), pp. 11–13, Figs. 5–6; No. 3 (February 1), pp. 21–24, Figs. 7–8.

*"The Geographic-Geological Distribution of the Petroleum Deposits of Greater Germany and Their Stratigraphic Classification," by W. Haack. *Petrol. Zeit.*, Vol. 35, No. 5 (Berlin, February 1, 1939), pp. 61-62; 1 map. In German.

ILLINOIS

Oil and Gas Development Map of the Noble Area (Ts. 1–3 N., Rs. 9–11 E., 14 W., Noble and Schnell fields). *Illinois Geol. Survey*. Scale 2 inches = 1 mile. Blue-line prints obtainable from map agent, 305 Ceramics Building, Urbana. Price, $0.60.

Oil and Gas Development Map of the Clay City Area (Ts. 1–3 N., Rs. 6–8 E., Clay City, Flora, Cisne, and Rinard fields). *Ibid.*

IRAN

*"Iranian Petroleum in Ancient and Medieval Times," by L. Lockhart. *Jour. Inst. Petroleum*, Vol. 25, No. 183 (London, January, 1939), pp. 1–18; 5 figs.

JUGOSLAVIA

Bull. Geol. Survey Jugoslavia, Vol. 6 (Beograd, 1938). Edited by Milan T. Luković. 272 pp., 21 pls. of figured fossils and photomicrographs. 6.625×9.5 inches. Paper covers. Contains the following articles and seven others (on mineralogy, etc.).

1. "Tectonic Movements in Eastern Serbia following the Formation of the Overthrusts," by M. T. Luković. Pp. 5–13, Russian; 13–23, English.

2. "Promina Beds at Velebit and Lika," by J. Poljak. Pp. 32–33, English; 3 photographs.

3. "Fossiliferous Beds of Kimmeridgian, Tithonian, Valanginian, and Hauterivian at Beograd," by Miroslav Jočanin. Pp. 35–69. German; 9 figs., 2 pls.

4. "Geologic Observations in the Vicinity of Metlika in Slovenie, in Relation to the Discoveries of *Ellipsactinia* Limestones," by Vojislav Čubrilović. Pp. 81–82, French résumé; 1 fig.

5. "Early Paleozoic Facies in Western Serbia," by V. Simić. Pp. 105–08, German summary.

6. "Synclinal Paleozoic in the Region of the Village of Plažane North of Despotovac and Its Relation to the Mesozoic Limestone (Eastern Serbia)," by Miloš N. Pavolovic. Pp. 117–20, French résumé; 6 figs.

7. "The Beds at Loftusia and the Question of the Presence of Marine Eocene in Western Serbia," by Branislav Milovanović. Pp. 129–34, French résumé; 2 pls.

8. "Note on the Geology of Kosmaj," by Radoslav N. Jovanović. Pp. 152–54, German summary; 4 figs., 1 pl.

9. "The Oligocene Flora at Kremma near Užice," by Dragutin Anić. Pp. 197–201, German summary; 11 pls.

10. "Some Trilobite Remains in the Upper Carboniferous of Lika in Croatia," by V. Simić. Pp. 212–13, German summary; 1 pl.

11. "Paleontologic Notes on the Environs of Berane," by V. Simić. Pp. 219–20, German summary; 1 pl.

Bull. Geol. Survey Jugoslavia, Vol. 7 (Beograd, 1938). Edited by Milan T. Luković. 340 pp., 13 pls. of figured fossils and photomicrographs. 6.625×9.5 inches. Paper covers. Contains the following articles, and five others (on mineralogy, etc.).

1. "Geology of the Eastern Portion of the Crna Gora (Kara-Dag) Mountain (Southern Serbia)," by M. T. Luković. Pp. 25–27, English summary; 5 photographs, 1 folded geologic map.

2. "Geology of the Region of Banjska," by V. Simić. Pp. 59–62, German summary; 18 figs., 1 geologic map.

3. "Structure and Tectonics of the Ovčar-Kablar Pass (Western Serbia)," by B. Milovanović. Pp. 92–94, French résumé; 9 figs.

4. "Preliminary Geologic Research Prizren Sheet (Southern Serbia)," by Miloš Pavlović and Vojislav Čubrilović. Pp. 112–14, French résumé; 9 figs.

5. "Geologic Structure of Vinodol and Surroundings," by Vojislav Čubrilović. Pp. 130–35, German summary; 3 figs., 1 folded geologic map.

6. "Fossiliferous Beds of Upper Paleozoic in Eastern Monténégro," by V. Simić. Pp. 151–52, French résumé; 3 figs.

7. "Note on Paleontology and Stratigraphy of the Cretaceous in Sumadija," by V. Mikincic. Pp. 160–66, German summary; 1 pl.

8. "Note on Miocene Croatian-Slavonian Echinoids," by J. Poljak. Pp. 200–03, German summary; 9 pls.

KANSAS

*"Geology of Northeast Kansas Sector of Forest City Basin Justifies Drilling," by Hugh McClellan. *Oil and Gas Jour.*, Vol. 37, No. 40 (Tulsa, February 16, 1939), pp. 26–27, 38; geologic map and section.

LOUISIANA

*"Oil Development in Louisiana during 1938," by Donald Goodwill, Jr. *Louisiana Conservation Review* (New Orleans, Winter, 1938–39), pp. 7–10; 8 photographs; table of discoveries in South Louisiana and North Louisiana, 1938.

NEW JERSEY

*"Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain: Part III: Barnegat Bay, New Jersey, Section," by Maurice Ewing, George P. Woollard, and A. C. Vine. *Bull. Geol. Soc. America*, Vol. 50, No. 2 (New York, February 1, 1939), pp. 257–96; 16 figs., 5 tables.

NEW MEXICO

*"Geologic Structure of Bueyeros Carbon Dioxide Area, Harding County, New Mexico," by J. Charles Miller and Merle Q. Dannettell. *U. S. Geol. Survey* map, described in *U. S. Dept. Interior Press Release* (February 17, 1939). Map obtainable from the director of the U. S. Geol. Survey, Washington, D. C., or from the supervisor of the Oil and Gas Leasing Operations, Box 997, Roswell, New Mexico.

POLAND

**Geological Map of the Eastern Carpathians*. Edited by K. Tolwiński. Carpathian Geological Survey, Boryslaw, Poland (1939). 2 sheets, each approx. 24×42 inches. Scale, 1:200,000. In colors, showing geology and oil and gas areas. Contains small insert map, in colors, showing geology of region between the Black and Baltic seas (scale, 1:7,500,000).

ROCKY MOUNTAINS

**Résumé: Rocky Mountain Oil and Gas Operations*, edited by C. E. Schoenfelt. Published by Petroleum Information, Inc., Continental Oil Building, Denver, Colorado. 156 multigraphed pages. Contains structure maps. The seventh annual volume of a series of compilations of pertinent data affecting the search for oil and gas deposits in Rocky Mountain region.

TEXAS

*"New Discoveries Add to Knowledge of Sparta-Wilcox Trend," by John D. Todd and Frank C. Roper. *Oil Weekly*, Vol. 92, No. 10 (Houston, February 13, 1939), pp. 18–22; 5 figs.

TUNISIA

"Search for Oil in Tunisia," by F. W. J. Saunders. *Petrol. Times* (London, November 12, 1938), pp. 644–45. *Abstract in *Jour. Inst. Petrol.*, Vol. 25, No. 183 (London, January, 1939), p. 6 A.

URUGUAY

*"Devonian Fossils of Uruguay," by R. Mendez-Alzola. *Geol. Inst. Uruguay, Bol. 24* (Montevideo, June, 1938), pp. 3–115; 1 sketch map, 2 pls. of photographs, 12 pls. of figured fossils.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 4 (APRIL, 1939), PP. 618-620

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Paul F. Clement, Bakersfield, Calif.
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Vern A. Hardin, Shreveport, La.
H. W. Bell, Roy T. Hazzard, Joseph Purzer
Frederick T. Jensen, Centralia, Ill.
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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 4 (APRIL, 1939), PP. 621-622

Memorial

ARTHUR CLIFFORD VEATCH
(1878–1938)

Arthur Clifford Veatch was born in Evansville, Indiana, October 26, 1878, and died at his home in Port Washington, Long Island, December 24, 1938. He received his collegiate training in Indiana University (1896, 1898), Cornell University (1898, 1900–01), and the University of Wisconsin (1905). During the period from 1896 to 1905, he also taught mathematics and physical geography in the high school at Rockport, Indiana; was in charge of areal and stratigraphic geology in the Cornell School of Field Geology; was a petroleum geologist at Beaumont, Texas; was assistant geologist and later geologist on the Louisiana Geological Survey and professor of geology at Louisiana State University; and was a member of the United States Geological Survey beginning in 1902. On April 16 of that year, he was married to Caroline Hornbrook Evans, of Evansville, Indiana, who survives him.

On the United States Geological Survey, he was assistant in charge of underground water investigations in Arkansas, Louisiana, and Long Island (1902–1904); assistant geologist (1904–1906), and geologist (1906–1910). During this connection, in addition to other duties, he served as special commissioner, appointed by President Theodore Roosevelt, to investigate the mining laws of Australia and New Zealand in 1907–1908, and organized and was first chairman of the Land Classification Board (1908–1910).

He was chief geologist of the General Asphalt Company in Venezuela and Trinidad in 1910–1911; in charge of oil exploration for the foreign department of S. Pearson and Son, Ltd., with headquarters in London, England, 1913–1919; and in charge of the exploration department of the Sinclair-Consolidated Oil Corporation, 1919–1928; and a consulting geologist with an office in New York City since 1928.

The breadth of Dr. Veatch's professional and scientific interests, as well as the recognition he received as a scientist, is indicated by his fellowship or membership in the American Association for the Advancement of Science, Geological Society of America, Society of Economic Geologists, American Institute of Mining and Metallurgical Engineers, Seismological Society of America, American Association of Petroleum Geologists, Mining and Metallurgical Society, Washington Academy of Science, Geological Society of Washington, American Geographical Society, Royal Geographical Society, and Geological Society of London. He became a member of the American Association of Petroleum Geologists in 1920 and was chairman of the committee on international relations from 1921 to 1923. He was active in the affairs of the Society of Economic Geologists, serving as councilor and as member of the executive committee for some years, and as president-elect for 1938. His death occurred only a few days before he would have become president.

Unfortunately for the science of geology, Dr. Veatch's administrative duties and the confidential nature of much of the information he accumulated during the latter part of his career prevented his publishing the results of many researches which would have been of great scientific value. Indeed, the breadth of his interests and his intense activity in pursuing the solution of the new problems which always opened for him as old ones approached solution

were in themselves deterrents to publication. It seemed as if he could not take time for the comparative drudgery of preparing manuscript on a problem that had been solved so long as there were so many interesting new problems coming up for investigation.

At that, more than thirty titles are listed to his credit in the bibliographies. Among these the "Outlines of the Geology of Long Island" with the accompanying paper on "Underground Water Conditions of Long Island" and "Geology and Underground Water Conditions of Northern Louisiana and Southern Arkansas," both published as Professional Papers of the United States Geological Survey in 1906, are standard works of reference, and the latter is still well and favorably known to geologists of the Gulf Coastal Plain. His papers on "The Shreveport Area" and "The Five Islands" published in the Report of the Geological Survey of Louisiana for 1899 are remarkable contributions from a man barely 20 years old. His last major publication was "Evolution of the Congo Basin" published as Memoir No. 3 by the Geological Society of America in 1935.

All his writings show not only his exceptional ability to see physiographic and geologic relationships in the field but to express them in clear and concise English as well as by his own maps and sketches.

His major geologic interest the last few years of his life was in an investigation of submarine topography, which resulted from his studies of the Congo River and the canyon which extends from its present mouth across the shelf and down the continental slope. He arranged a coöperative project between the United States Coast and Geodetic Survey and the Geological Society of America, which has led to the detailed mapping of nearly all the continental shelf and of the continental slope to a depth ranging from 6,000 to 10,000 feet, from the entrance of Chesapeake Bay northeastward to some distance beyond the eastward extremity of Long Island.

This survey has shown that the slope instead of being smoothed by deposition, as had previously been assumed, is, in this area and to a depth of 10,000 feet and more, dissected by dendritic drainage similar in all respects to that developed on land, with the canyons of the major streams rivaling the Grand Canyon of the Colorado in depth below the interstream surfaces. Although greatly handicapped by illness for the last 2 years, he continued work on this problem until within less than a week before his death, and left the project well on the way toward completion and publication. This work, which strikes so deeply into fundamental concepts of geology, may well prove to be the climax of a remarkable career as a geologist.

Personally, A. C. Veatch was a man of striking appearance and of peculiar charm, in the best sense of that word. He had no hesitation in expressing his views on a subject on which he was interested, whether or not they were likely to agree with those of his hearers, but without dogmatism or offense. He was a hard worker, with little respect for regulation office or field hours, and expected similar interest on the part of his co-workers, but was an interesting and inspiring companion at work. He had a great interest in rare and unusual flowers and shrubs, in which Mrs. Veatch shared fully. They, as well as their friends, took great pleasure in their beautiful garden on the terraced hillside at their Port Washington home.

L. C. Snider

New York City
February 27, 1939

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 4 (APRIL, 1939), PP. 623-624

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Newly elected officers of the South Texas Geological Society are: president, WILLIS STORM, Petro Royalty Corporation, San Antonio; vice-president, DALE L. BENSON, Sinclair Prairie Oil Company, Corpus Christi; secretary-treasurer, IRA A. BRINKERHOFF, Stanolind Oil and Gas Company, San Antonio, Texas. EDWIN L. PORCH, JR., San Antonio, was elected a member of the executive committee.

DONALD C. BARTON spoke recently before the Shreveport Geological Society. His subject was "The Art of Reading Aerial Photomosaics."

SAM F. BOWLBY, chief exploitation engineer for the Shell Petroleum Corporation, Houston, Texas, was the guest speaker on February 28 before the Petroleum Engineering and Geology Club at the Texas A. & M. College, College Station. His subject was "What a Major Oil Company Expects of Its Petroleum Engineers." The meeting was attended by 196 members.

An illustrated address was given by FREDERICK G. CLAPP before the New York Mining Club, February 7, entitled "Afghanistan."

V. E. COTTINGHAM, recently director of production and engineering for the Texas Railroad Commission, is chairman of the North Basin Pools Engineering Committee, in Texas.

G. E. ANDERSON, of the School of Geology at the University of Oklahoma, Norman, discussed "Origin of the Color Line in Permian Sediments from Kansas to Oklahoma," before the Oklahoma City Geological Society, in February.

LOUIS DESJARDINS, of the Aero Exploration Company, Tulsa, spoke on "Geologic Mapping of Oklahoma Formations and Aerial Photographs," before the Tulsa Geological Society, March 6.

KARL SUNDBERG, managing director of Aktiebolaget Elektrish Malmletning, died in Stockholm, Sweden, February 3, 1939.

GLENN SLEIGHT, field geologist and chief scout for the Sun Oil Company, at Mount Pleasant, Michigan, has been elected president of the Michigan Scouts Association.

W. B. BERWALD, for many years with the United States Bureau of Mines, recently stationed at Bartlesville, Oklahoma, is now on the engineering staff of the Ohio Oil Company.

CHARLES H. TAYLOR, of the School of Geology at the University of Oklahoma, spoke before the Oklahoma City Geological Society, February 27, on "The Wichita Mountains of Southwestern Oklahoma."

CHARLES W. HONESS has been transferred from Wichita, Kansas, to Kentucky. His address is the Gulf Refining Company, Box 594, Owensboro, Kentucky.

The Geological Society of America will join with Section E of the American Association for the Advancement of Science in the summer meetings to be held in Milwaukee, June 19–24. The Society will hold a joint meeting with the Cordilleran Section, at Berkeley, California, August 8–10. The Paleontological Society, the Seismological Society of America, and the Society of Economic Geologists expect to meet in Berkeley at the same time.

The Pan-Pacific Science Congress will hold meetings in Berkeley, July 24–August 5, and at Stanford, August 6–12.

The International Union of Geodesy and Geophysics will be held in Washington, D. C., September 4–15, under the auspices of the American Geophysical Union in coöperation with the National Research Council.

LESTER S. THOMPSON, geologist with the Basrah Petroleum Company, Ltd., Basrah, Iraq, has been engaged in a geological reconnaissance of Oman (Eastern Arabia).

F. B. PLUMMER, of the University of Texas Bureau of Economic Geology, Austin, addressed the Houston Geological Society, March 9, on the subject, "Methods of Reducing Water in Wells Producing Both Oil and Water by Means of Chemicals."

KENNETH B. NOWELS has resigned from the Forest Oil Corporation and is beginning private practice at Abilene, Texas. Nowels has specialized in water-flooding work.

The New Mexico Geological Society has elected the following officers: president, CARL F. BARNHART, Amerada Petroleum Corporation; vice-president, R. L. VOSS, Gulf Oil Corporation; secretary-treasurer, JOHN KELLY, New Mexico Proration Staff, all at Hobbs, New Mexico.

FRANK BROOKS, geologist with the Gulf Oil Corporation at Wichita, has been transferred to the Indianapolis, Indiana, division headquarters.

H. E. CHRISTLER has accepted a position as geologist with the Indian Oil Concessions, Ltd., 2 Bath Island Road, Karachi, India.

H. S. MCQUEEN spoke on the "Geology of the Forest City Basin," before the Tulsa Geological Society, March 20.

JOHN F. WEINZIERL, consulting geologist of Houston, Texas, addressed the Shreveport Geological Society recently on "Geophysics in Relation to Geology."

The Geology Club of the University of Tulsa sponsored a field trip to Marble City, Oklahoma, March 11.

CECIL HAGEN is chief geologist for the Superior Oil Company, succeeding H. M. HORTON.

SAM GRINSFELDER, recently at Dominguez, California, for the Union Oil Company of California, is in charge of the company's operations east of the Rocky Mountains.

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Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

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SHREVEPORT, LOUISIANA

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Bay Oil Corporation, 911 Commercial Bank

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

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Shell Petroleum Corporation

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

MICHIGAN

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Gulf Oil Corporation, Saginaw
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Michigan Geological Survey, Lansing
Business Manager - - - - Helen Martin
Michigan Geological Survey

Meetings: Monthly dinner meetings rotating between Saginaw, Mt. Pleasant, and Lansing. Informal dress.

TEXAS

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Consulting Geologist, Trinity Life Building

Vice-President - - - - - J. H. Markley
The Texas Company

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The Pure Oil Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

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Stanolind Oil and Gas Company

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Speed Oil Company

Regular meetings held every Thursday at noon (12 o'clock) above Kelly's Restaurant, 910 Texas Avenue. For any particulars pertaining to the meetings write of call the secretary.

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814 Hamilton Building

Luncheons and evening programs will be announced.

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Executive Committee - - - - - E. L. Porch

Meetings: Third Friday of each month at 8 P.M. at the Petroleum Club. Luncheons every Monday noon at Petroleum Club, Alamo National Building, San Antonio, and at Plaza Hotel, Corpus Christi.

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Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

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University Lands

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Meetings will be announced

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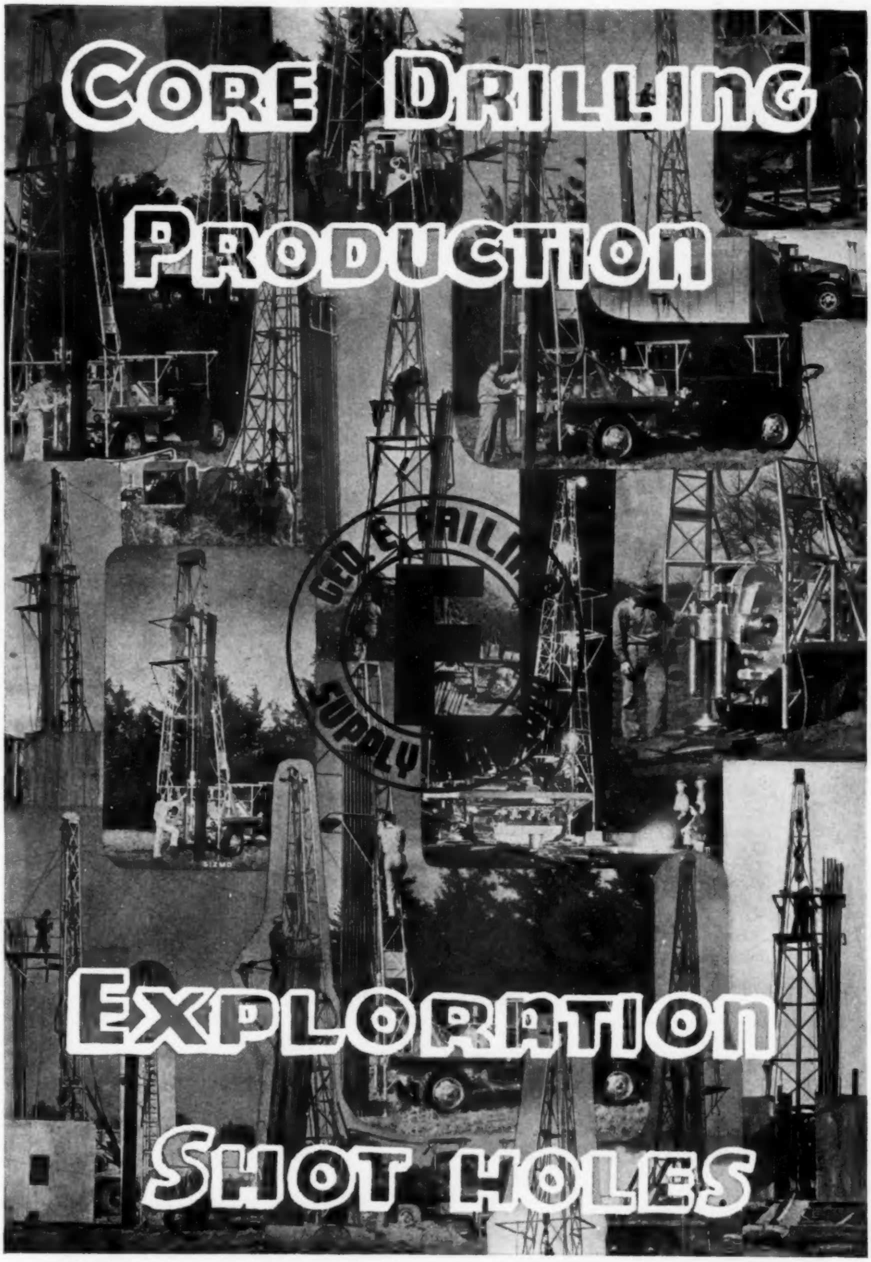
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